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CONFIDENTIAL

FINAL REPORT NO.

CLOCKWORK DELAY MECHANISM, 24 HOUR

Work Orders CK-15-529, CK-15-529.1

and CK-15-529.2

C-59411

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I. INTRODUCTION

The history of demolitions and active sabotage work is in large part made up of instances in which explosives, incendiaries and other media have been initiated to produce damage at a fixed, predetermined time delay after setting. The reasons for use of a delay period are twofold; first, to insure the safety of personnel setting the charges and, second (and perhaps more important in sabotage work), to wreck havoc at a time when its gross effects would be at a maximum.

Historical methods by which delayed initiation has been produced have been many, each reflecting the limitations imposed by the timing elements available during the era of their use. The advent of accurate mechanical watch movements, however, did much to open up new fields of possibility in this work. By their use, the tactical employment of accurately and reliably timed events was greatly expanded, since the former limitations of short delay periods, questionable accuracy and extreme environmental sensitivity were in large part relaxed.

Introduction of the mechanical clockwork delay mechanism, however, brought with it the inherent problems of reliability, cost and, more recently, storage life. It is with the redesign of a 24-hour clockwork delay mechanism, based on the World War II, U. S. Navy Mark III device, and the solution of these inherent problems that this report is concerned.

II. SUMMARY AND RECOMMENDATIONS

Under the authority and funds provided by Work Orders QK-15-529, QK-15-529.1 and QK-15-529.2, redevelopment of the World War II Clockwork Delay Device, (U. S. Navy Firing Device, Mark III), and pilot production of 1,000 Clockwork Delay Mechanisms, 24-hour, were undertaken by Arthur D. Little, Inc. on April 23, 1951. The developmental work by ADL was accompanied by both model and production work by two subcontractors; Thomaston Special Tool Company of Thomaston, Connecticut, produced the devices minus the clockworks, and New Haven Clock and Watch Company of New Haven, Connecticut produced the clockwork movements and their accessories.

During the program, problems of various different sorts arose. Those regarding general design and performance criteria were resolved with the assistance of consultants who were experienced in the World War II effort along similar lines. Problems of tooling and production standards were resolved directly with the major subcontractors mentioned above. The personnel involved in the project, and the identity of their various organisations, are summarised in Appendix C.

An initial pilot lot of approximately one hundred devices was produced early in 1954. These devices were subjected to various test programs designed to determine their ease, reliability and accuracy of operation under varying combinations of temperature, humidity, pressure and time. The major questions of reliability and accuracy were considered not only from the field operations viewpoint; much attention was given also to the contributions of manufacturing and storage conditioning and their effect on the end performanse of the device. Each of these questions is discussed in more detail in the following sections of this report.

As a result of the program, Specifications and Drawings were developed, reflecting all recommended changes to bring the original U.S. Navy Firing Device, Mark III, up to date as a more reliable and accurate 24-hour delay mechanism. Under these Specifications and Drawings, a total of 1,072 devices were produced; 79 of these were designated as training devices not to be used for actual operations, and the remaining 993 were first-line operational units. These Specifications and Drawings are to be found in Appendices A and B of this report.

Although the redeveloped 24-hour clockwork delay mechanism is significantly better than its World War II predecessor as regards ease, reliability and accuracy of operation, it is subject to several severe restrictions which, in our opinion, should preclude its further manufacture in large quantities. In brief, the reasons for this belief are as follows:

1. Maximum delay is only 24 hours; This leaves a large long-time delay range which is uncovered except by the limited supply of J-Feder delay mechanisms and the nominal delay devices such as the time pencil, AC delay, etc.

   Recommendation: Any further efforts in the mechanical, clockwork delay field should be made toward a device capable of at least one week and preferably on the order of one month maximum delay.

2. The design is not symmetric about the firing pin center line; Contrary to the World War II situation which did not stress minimum clearance dimensions for many items, many present devices, to which the clockwork delay is applicable,

require smaller initiating mechanisms. A case in point is the Initiator; the Clockwork, because of its assymetric design, extends approximately one inch beyond the initiator tube diameter.

Recommendation: Future clockwork delay mechanisms be designed symmetrically about the firing pin axis.

3. The case design is non-cylindrical; The rectangular case is considerably more difficult to seal than is one of circular cross-section. The latter section is very inexpensively and effectively sealed by means of O-rings. The circular section is less expensive to machine and given dimensional tolerances are more easily achieved in rotating tools used to handle such shapes.

Recommendation: Future clockwork delay mechanisms be designed for cylindrical cases, in conjunction with (2) above.

4. The present design cannot be wound or set under water; the mechanism can be stopped at any time; These first two design features should be eliminated in order to insure a more versatile device; the last, to preclude tampering or disarming after it is once set.

Recommendation: The case, safety and starter design of future delay mechanisms should include these features.

III. CONTRACTUAL HISTORY

During the period from April 23, 1951 through June 30, 1955, covering the redevelopment and pilot production of the 24-Hour Clockwork Delay Device, the following Work Orders were issued to Arthur D. Little, Inc.:

Work Order and Date	Amount	Purpose
QK-15-529 April 23, 1951	$ 500.00	Initial investigation
Subtotal	$ 500.00	
QK-15-529.1 November 3, 1951	3,000.00	Clockwork development and consultants
February 26, 1952	3,000.00	
Subtotal	6,000.00	
QK-15-529.2 (P) April 11, 1952	69,443.00	Production of 1,000 mechanisms
May 19, 1952	8,000.00	Production of 1,000 watch movements
May 7, 1954	21,200.00	Continued testing of pilot lot, inspection of production lot, and unit packaging.
Subtotal	$98,643.00	
*Total Expended	$105,143.00	

"*These figures do not represent audited or accounting costs ......"

IV. WORLD WAR II PROTOTYPE CLOCKWORK DEVICE

A. GENERAL HISTORY

One of the oldest problems of Division 19 of OSRD was the development of a clockwork delay. Much work was done at the University of Chicago by Dr. M. S. Kharasch, but did not result in a suitable device. In January, 1943, when first contact was made with the Leeds & Northrup Company, all previous work on time delays of all types was disclosed. This included the Chicago work.

Because it was known that the Engineer Board at Fort Belvoir, Virginia, had three different clock manufacturers under contract to develop clockwork delays, no particular impetus was given to L & N as a contractor until late in February, when OSS, SOE, and Division 19 representatives gathered in Philadelphia and presented to Mr. B. J. Wilson of L & N samples of the various devices then available. At the same time requirements were framed for the development of a delay suitable for use with the Limpet. In addition, mechanical firing was specified, and it was hoped that this could be centrically designed. Contact was made also at this time with Mr. R. H. Whitehead of the New Haven Clock and Watch Company, and during March his interest and cooperation in the problem were secured.

At a large meeting in April, 1943, attended by the Honorable Morris Lubbock, Deputy Head of ISRB, and Wing Commander T. R. Bird, definite requirements were framed for a clockwork device. These included the specification that it should be insensitive to temperature change, vibration, magnetic field, shock, and immersion. In addition, it was pointed out that it should be based on a cheap watch movement to allow large production. In this meeting Mr. Wilson showed for the first time a prototype of the mechanical system he proposed to use in conjunction with a watch movement. This differed materially from the early Khrasch design utilizing an Elgin watch. The central firing feature was not preserved and seemed to be a small sacrifice for convenience and speed.

By June, 1943, Mr. Wilson had constructed in his shop the first 12-hour model, based on a New Haven movement, which was capable of a 5-minute setting accuracy by retention of the minute hand. This model underwent tests during the following weeks and later appeared so favorable that the Division decided upon a semi-production. At their request the Engineering and Transition Office proposed as contractor the Houston Company (SAC-27). The negotiations with Houston dragged, however, and eventually OSS felt itself in a position to begin its own procurement. Leeds & Northrup thereupon contacted the Automatic Temperature Control Company, located near them in Philadelphia. New specifications were prepared, and an OSS contract for 500 models was forthcoming.

Meanwhile, the British at Stations II and III had continued the development of a central firing unit based on the Eureka Clock, then used in British aircraft. This device was very cumbersome, large, and sensitive to shock. It did not survive the extended test program, and eventually SOE accepted the Leeds & Northrup device as a store.

At almost the same time that OSS began its contract, the DOLO Committee became aware of the development and brought it to the attention of the Navy for use of the Underwater Obstacles Group. Its acceptance by the Navy was immediate and startling; six thousand units were requested for delivery in two months. OSS and the Navy thereupon came to an understanding, by which the Navy took over the procurement contract and agreed to supply OSS and SOE with their much smaller requirements. The Bureau of Ordnance made a few minor changes in the Leeds & Northrup design, only one of which later turned out to be serious. This was the modification of the stiff dial which replaced the hour hand by a thin disc. This modification was later abandoned and the original design readopted (designated Firing Device, Mark III).

From November, 1943 to December, 1944, the Leeds & Northrup Company acted as consultants to the Automatic Temperature Control contract. This function was of the greatest value and convenience. In April, 1944, Mr. B. J. Wilson was so disturbed by the lack of Navy inspection and so fearful that serious trouble might therefore arise, that a meeting was held in Philadelphia Naval Inspection Board with the interested parties in attendance. The Navy accepted all the Leeds & Northrup suggestions for correction, and in addition re-inspected all the units which had been made. This confirmed Mr. Wilson's statements and the entire production, numbering several thousand units which had been made up to that time, was returned to the manufacturer for reconditioning. NRL tested the 12-hour delay also with, on the whole, more favorable results (NRL Report No. 80 of May 4, 1944, and No. 80A of August 2, 1944).

Meanwhile, Mr. Wilson had also been working on the development of a 24-hour model which he completed in June, when ten models were received by the Division and distributed to the interested Services. The 24-hour model was identical with the 12-hour model in all respects except for the gearing of the New Haven movement. Appraisal by OSS and the Navy resulted in a small procurement on their part.

In July, 1945 the existence of very small 8-day movements used in Naval aircraft came to the attention of the Division, and it was thought that these might be small enough to fit the case of the 12-hour and 24-hour delays. Mr. Wilson proceeded during the following months to show that this was possible, and in August, 1945, two models were received. These aroused the interest of the Engineers and OSS, but since their arrival coincided with V-J Day, no production took place.

NRL, throughout the program, was always of assistance in testing the different models. Their results obtained with the 24-hour production confirmed their earlier ones obtained with the 12-hour (NRL Report No. 193 of April 9, 1945 and No. 211 of May 30, 1945). Their conclusion was that both devices were "water-tight, rugged, not impaired by either a magnetic field or severe vibration, and capable of operating satisfactorily under all probable climatic conditions".

The 12-hour model was produced in large numbers (20,500) and of the 24-hour device, 1,500 were manufactured. The OSS and SOE use for either type was not limited to Limpets. Wherever an exact timing of an explosion was required this special time delay was available. In contrast to the Pencil, it was never intended as a general issue item but was reserved for special operations. The principal Navy use was in connection with the detonation of underwater explosive charges placed by the Underwater Demolition Groups which trained at Fort Pierce, Florida, and later performed such spectacular services in the Southwest Pacific.

B. DESCRIPTION OF WORLD WAR II PROTOTYPE CLOCKWORK DELAY DEVICE

Among the construction and operational features originally required were the following points, all of which were successfully overcome in all three models:

1. Accuracy of 15 minutes in the 12-hour delay, 30 minutes in the 24-hour delay, and 15 minutes in the 6-day delay.
2. Cheapness and robustness.
3. Ready setting and adjustment in the field.
4. Convenient pocket size.
5. Resistance to temperature change and deep immersion.
6. Safety and starting means operable under water.
7. Magnetic protection,

In general, the Mark III delay and its companion models consisted of an aluminum case case 2-9/16x2-3/8x1-5/16 in. with a transparent plastic window beneath which the dial and setting hands were visible. Two knurled thumb screws projected from the case; the one on the back operated the safety, and the one on the side started the device. Magnetic protection was provided by an iron back plate which carried two plugs, providing access for winding of the movement and setting of the delay. All joints were equipped with gaskets or stuffing boxes to insure waterproofness. The particular, cheap pocket-watch type movement used was a back-wound and back-set type made by the New Haven Clock and Watch Company. It required only slight modification for immediate insertion in the Mark III case. The hour hand was replaced by a cupped disc having a narrow slot in the circumference and the internal friction drive was modified to increase its reliability of drive and minor changes were made in other elements. The minute hand was retained to secure precision of setting, a feature missing in most mechanisms of the type available at that time.

When the starting knob was turned to running position, the movement balance wheel was automatically given a kick to insure its starting, and the tripping lever moved downward to make contact with the hour disc. As time passes, the hour disc moved under this lever until the previously-mentioned slot coincided with a pin in the end of the lever. When this occurred the lever dropped toward the center of the hour disc and, by a series of levers and latches, a firing pin, restrained against a 15-lb. spring, was released to accomplish the detonation mechanically. This pin was located in the side of the aluminum case so that the unit is asymmetric. A safety was provided by means of a removable member interposed between the striker and the detonating train. Should premature release occur, the striker was caught by the safety. In the field operation, the mechanism would be started and the safety then removed in accordance with custom.

The 24-hour delay was identical with the 12-hour except for the substitution of a disc which makes a complete revolution in 24 hours instead of in 12. Naturally, a scale having 24 divisions, instead of 12, was also provided. The multi-day device, which in practice was found to be reliable up to 6 days, had two concentrically mounted discs, the outer one rotating once in the maximum delay period of 6 days and the inner one rotating once in 12 hours. A minute hand was retained, together with the usual hour and minute dial, so that the setting was as accurate as with the 12-hour delay. The tripping lever was held by the outer disc until the slot in it permitted it to fall through. It then rested on the inner disc until the proper hour and minute arrived, when the slot in the second disc allowed the lever to continue its travel, trip the latch, and release the linkage and striker.

The Final Report, containing detailed data on World War II, clockwork developments is covered in Division 19, Serial No. 31, Section 2, of July 15, 1945, submitted September 7, 1945.

V. DESCRIPTION OF THE CLOCKWORK DELAY MECHANISM, 24-HOUR

The Clockwork Delay Mechanism, 24-Hour, is a precision-type firing device which may be set for delay periods varying from 5 minutes to 23 hours 45 minutes. As implied by its name, the device is driven by a watch mechanism.

The physical size of the device, without accessories, is approximately 2-9/16" x 2-3/8" x 1-5/16"; the unit weighs approximately 1.18 lbs. (537 gms.). This relatively high unit weight is caused by the die-cast zinc case in which the watch movement, dials and firing linkage are housed. Figure 1 shows the face of the device. In its physical aspects the redeveloped device is generally similar to its World War II predecessor, described in Section III of this report.

The Clockwork Delay Mechanism is designed to fire two (2) types of primer-detonator combinations. The first combination, the standard coupling base primer and Corps of Engineers non-electric detonator, can be fired without a special adapter of any sort. The second, the M-34 detonator, requires a special, stab-action adapter which is supplied as accessory equipment with the packaged device. With these two, the Clockwork Delay Device can be used with most of the explosive and incendiary devices used by the Client at the time of the development program. Because of the non-central location of the firing pin, however, the Clockwork device will not necessarily have the same minimum clearance dimensions as the device with which it is to be used.

In operation, the Clockwork Delay Mechanism can be employed at temperatures between an extreme low of -45°F and an extreme high of +160°F. Accuracy at these limits, however, is questionable, since the watch mechanism tends to run "slow" (i.e., the timed delay is actually longer than it should be) under both extremes. Accuracy within ± 3 minutes in 24 hours is readily

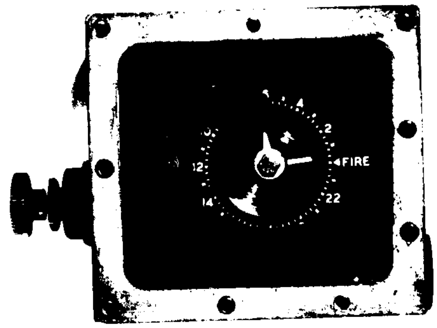

Fig. 1: 24-Hour Clockwork Delay Mechanism, with transparent face removed, showing dial and firing linkage.

Fig. 2: 24-Hour Clockwork Delay Mechanism Watch Movement

achieved within the temperature limits of -10°F to 120°F. At 70°F, the accuracy of the delay period is within +0 and -2 minutes in 24 hours; this accuracy is specified as a requirement for final acceptance inspection. The case and its adapter are water-and oil-tight under static pressure heads of 50 feet of water. By means of careful selection and preparation of a particular unit, water tight integrity at equivalent depths up to 100 feet of water have been achieved. The gaskets and seals of the device are completely resistant to water, lubricants and fuels and most solvents under the pressure heads mentioned above.

The packaged Clockwork Delay Mechanism includes several accessories for its preparation and adaptation. These items include a winding stem; a special adapter for the M-34 detonator; a coupling base adapter and primer; an M-34 detonator; a coil of wire for attaching the device to targets; and a tube of obscuring compound to cover the dial face and prevent later observation of the time setting. The entire kit is enclosed in a tear-strip can of approximately 4-1/8" D x 4-1/4" high.

VI. DEVELOPMENT HISTORY

A. GENERAL BACKGROUND

The period from April 23, 1951 to approximately December, 1952 marked the formative period of the Clockwork Delay project. During this time the primary tasks were those of establishing design requirements and criteria, locating potentially interested manufacturers and, finally, working with these manufacturers to obtain firm bids for production. Only after the successful completion of this period could the project planning be implemented by funds for the required tooling, equipment and labor to produce the Clockwork device.

This period, strangely enough, was perhaps one of the most difficult of the entire program. The establishment of operating characteristics and design criteria was readily made with the mutual cooperation of the Client, ADL and two major consultants, Leeds & Northrup Company and Automatic Temperature Control Company; both of Philadelphia. Difficulty began, however, when the great majority of firms contacted and requested to bid on this project were unable to do so for a number of reasons. These firms represented a good cross-section of the watch, clock and timer mechanism manufacturers in the United States; their reasons for refusal, for the most part, were based on their already overloaded production facilities being unable to take on further development and production.

It was not until October, 1951 that any bid was received. At this time, the Automatic Temperature Control Company of Philadelphia, Pa., the previous manufacturer of the Navy's Demolition Firing Device, Mark III, submitted a bid for the cases and mechanisms, minus the watch movements. It became quite apparent, then, that the subcontracting for the project would probably have to be made in two separate parts, e.g., for the movements and the mechanisms separately.

With this in mind, further attempts were made to obtain separate bids from other manufacturers and from those which had already indicated their inability or unwillingness to bid on the entire unit. Finally, two (2) clockwork manufacturers, Inghram and New Haven, and two (2) general manufacturers, Automatic Temperature Control and Thomaston Special Tool Company, submitted bids on the separate items. Although no production commitments were made at this particular time, ADL was then able to outline the fund requirements anticipated for the project and request a work order from the Client. On April 11, 1952, the Client authorized $69,443 for the mechanisms, and on May 19, 1952, $8,000 for watch movements; both of these authorizations were based on the lowest quotations received for each of the two major subcontract items.

On May 19, 1952, however, Inghram Watch Company withdrew its verbal quotation on the basis that a very recent Armed Forces contract threatened to overload their facilities. This withdrawal left only New Haven Clock and Watch Company as a potential source of watch movements, and a choice of Automatic Temperature Control and Thomaston Special Tool as sources of the mechanism. Thomaston, being both the lower bidder and well qualified for the work, was awarded the subcontract on December 8, 1952; New Haven Clock and Watch Company being the only available source of watch movements remaining, was awarded an initial prototype subcontract on December 16, 1952.

B. DESIGN CRITERIA

As previously mentioned in earlier parts of this report, the only existing prototype of a clockwork delay mechanism suitable for the Client's purpose was the World War II, U. S. Navy Firing Device, Mark III. Of the three models of this device available, the 12-hour model was the closest to the particular problem at hand. It was an early decision by the Client that, as far as possible, the new 24-hour clockwork delay mechanism should follow this Mark III design, in order to make maximum use of previous design and tooling experience. Quite naturally, this previous experience had uncovered undesirable features of this design; the early development program for the 24-hour clockwork delay, therefore, seriously considered these features. This experience, coupled with a listing of desired engineering characteristics formulated by the Client for their particular needs, provided the foundation for the early design work. A list of these desired engineering characteristics is as follows:

1. Timing element inexpensive and readily available.
2. Both minute and hour indication for greater accuracy of setting and reading.
3. Unaffected by temperature change from -40°F to +160°F.
4. Unaffected by severe vibration, such as would be encountered in airplanes, trucks and rough handling, while in either the shipping or operation condition.
5. Accurate within 5% of delay time set.
6. Inaudible to normal hearing at 6 feet or less.
7. Operable under 25 feet of water.
8. Unaffected by weathering and humidity.
9. Positive safety which cannot be removed if firing pin has been released.

10. Positive start and stop.
11. Can be set to fire at any predetermined period of time from 15 minutes to 24 hours and if feasible up to 7 days.
12. Can be wound and set in field with no tools other than those in container. Operator should be able to wind and set device with gloves on.
13. Quickly, easily and safely attached or installed.
14. Simple to manufacture and operate.
15. Must initiate suitable detonator.
16. Not affected by magnetic field.
17. Minimum shelf life of 5 years.
18. Minimum use of stragic materials.
19. Compact.

The following characteristics are desirable but not necessary:

20. Operator can see amount of time remaining before firing.
21. Time remaining can be changed after setting.
22. Operator has choice of whether or not device can be stopped and safety reinserted.
23. Individual device can be tested and reset.
24. Luminous dial and indicators.

The Mark III device was designed during World War II by the Leeds & Northrup Company of Philadelphia, and manufactured by the Automatic Temperature Control Company, also of Philadelphia. It was to these sources that Arthur D. Little, Inc. turned for advice and consultation in the evaluation and early development work for the new clockwork delay mechanism. The previous war-time experience of these companies proved of great value, and both were anxious to cooperate to the fullest extent possible. It was only after the initial production of two pilot models of the mechanism and its watch movement that the consulting services of these two firms declined in value.

C. WATCH MOVEMENT AND ACCESSORIES

New Haven Clock and Watch Company, New Haven, Connecticut, designed and manufactured the watch movement used in the World War II Firing Device, Mark III. The early consultation with Leeds & Northrup Company, who did the previous over-all design work on the device, indicated that a large number of the watch movement in the devices produced on this Navy contract did not run. Leeds & Northrup stated that it was difficult to determine the exact causes of this large failure, but they found records indicating that something of the order of 40 - 50% of the movements were rejected prior to their installation into the device. After installation, approximately 25% of those previously accepted were rejected during run-in. They also indicated that, by a very rigid double-selection inspection, the failure rate of the World War II device was reduced to approximately 9.5% after they were received in the field. Leeds & Northrup indicated that the causes for this large failure rate was believed to lie in the design and manufacture of the watch movements.

One of the earliest considerations in the 24-hour clockwork mechanism program was summed up in the term, "the watch must run"; this reflected the feeling that, in spite of all other limitations, the redesign mechanism must function when delivered in the field. On this basis, Leeds & Northrup undertook an initial evaluation of the various sources of failure in both watch mechanism and the firing linkages of the World War II device. In this, they were greatly assisted by the report by Mayo, NOLM Report 7350. It was their belief that the faults in watch making which had caused the large number of failures could be defined as:

a. Excessive gear backlash.

b. Excessive pinion end play.

c. Excessive pinion side play.

All of these faults can be summed up in the statement that the original watch movements were not designed or manufactured with sufficient attention to tolerance control. In addition, there were indications also that the New Haven production techniques did not provide for adequate movement cleaning, deburring, chip removal and prevention of general contamination.

The summarization of Leeds & Northrup's early study was that the watch movement used to power the 24-hour clockwork delay mechanism, while of a relatively inexpensive nature, could not be the "dollar watch" previously used. On this basis, various manufacturers of the so-called "dollar watch" were contacted in an effort to determine whether or not their standard watch mechanisms could be improved and adapted for this application. This investigation proved that only two, New Haven and Inghram, manufactured movements suitable for consideration. Of the two the standard Inghram movement appeared to be of the better quality; its design, however, would of necessity have to be changed in many details in order to adapt it for this use. The New Haven movement, since it was the original basis for the Navy's Mark III device, quite naturally did not require any major changes except to provide for back winding and setting. It was not until Inghram voluntarily removed themselves from bidding that the design was forced, by default, to base the redeveloped unit on the New Haven movement.

Early discussions with the New Haven Clock and Watch Engineering Department indicated that the design changes and increased tolerance control believed desirable for this application could be quite easily incorporated into their basic "dollar" movement. On this basis, New Haven was asked to build immediately two movements incorporating all of the changes believed desirable. After considerable delay in their manufacture, these movements were incorporated into two pilot devices and, under test, functioned quite satisfactorily.

Additional small changes, including alterations of the drum, hands luminous paint and other small details, were mutually decided among the Client, Arthur D. Little, Inc. and New Haven. A second production of approximately 100 movements, incorporating all of the design changes, was made and tested in pilot production mechanisms at the Reservation. The results of these tests confirmed the previous indications that these design changes allowed successful use of the "dollar" movement; New Haven then undertook the remaining production of 1,000 units at a unit cost of approximately $15.64.

In summary, the design changes made to the basic watch movement and its accessories are as follows:

D. ALTERATIONS TO WATCH MOVEMENT AND ACCESSORIES

The following is a list of the design changes made to both the commercial version of the New Haven Clock and Watch Company's "dollar movement" and to the original United States Navy Firing Device, Mark III, in order to bring the Clockwork Delay Mechanism 24-Hour to its present stage of design:

1. Movement

   a. Tightened tolerance control to limit end play between the center pinion shoulders and the front and back movement plates.

b. Tightened tolerance control to reduce end play of the hour drum, in order to eliminate rubbing of the drum and the tripping lever.

c. Tightened tolerance control to eliminate side play of the center pinion; this was achieved by better tolerance control of both the center pinion diameter and the movement plates hole location and diameter.

d. Changed the "under-dial" gear train from 12/1 to 24/1, and tightened the tolerance control of both gear location and contour in order to eliminate gear backlash and binding in the train.

e. Modified the existing click in order to provide additional main spring back-off when the spring was fully wound; this was to prevent both over-winding and breakage of the spring as well as failure to start as a result of high spring friction.

f. Tightened the tolerance control of the fit between the front and back movement plates at the movement pillars; made the pillars hollow in order to accept mounting screws.

g. Added bevel shaped jewels to the balance staff and plugs, and specified higher polishing of the lever andescaped wheel pivots in order to reduce the train friction and dead-beat angle.

h. Specified a non-magnetic and non-temperature sensitive hair spring material.

i. Increased the diameter of the back dial setting knob to enable easier and finer settings to be made.

j. Enlarged the peep hole in the top movement plate to enable better visibility of the escape wheel for purposes of checking movement operation.

k. Added a luminous paint line on one spoke of the escape wheel to allow checking of movement operation through the peep hole in the dark.

l. Changed the previously used slotted back winding stem to a 3/32" square stem.

m. Made the final inspection and acceptance specifications for the movement considerably more rigid than previously used.

2. Dials, Hands, Etc.

a. Modified the dial face for 24-hour operation.

b. Changed luminous paint from green to white in order to increase night-time visibility (changed to Canadian, Radium and Uranium Corporation #183).

c. Changed contour of dial plate to eliminate accumulative tolerance difficulties in assembly; enlarged peep hole.

d. Increased the allowable tolerance of the dial stock in order to conform with industrial standards.

e. Substituted a longer and slimmer minute hand for that originally used, in order to reduce parallax and enable more accurate setting.

f. Changed hour drum spot to an embossed and luminous paint filled line on the hour to enable better visibility.

g. Changed finish of the dial, hand, and retainer nut to dull black, in order to reduce reflected light.

h. Removed threads from the hand; hands held in place by jamming action of nut.

3. Accessories

a. Substituted new square shank winding stem for the original key, and increased the over-all length of the key 1/2" to allow easier winding under operating conditions.

E. MOVEMENT LUBRICATION

One of the earliest considerations in the problem of specifying a suitable watch movement was that of its lubrication. The concern shown over lubrication by all those involved in the project was ample indication of its importance.

The first decision to be made was that of whether or not any lubrication was to be used. It is a well-known fact that unlubricated, or "bare", watch movements operate exceedingly well at low temperatures. Since the low temperature operation of the prospective device was of primary concern, the possibility of using bare movements was given serious consideration. On the other hand, it has been the long experience of both the Government and civilian firms in the manufacture, storage and use of fuse mechanisms that a bare movement exhibits poor storage characteristics. Although the exact nature of these characteristics have never been well defined, it is felt that the high unit pressures existing in the movement bearings contribute to "freezing" and subsequent storage failure of these unlubricated devices. Since one of the primary considerations for the device was that the movements must run, regardless of its accuracy, it was finally decided that they should be lubricated in spite of the fact that this would very probably be detrimental to their low temperature performance.

The decision to lubricate the movements, however, was feinitely a "mixed blessing", since, as previously mentioned, it introduced additional problems of low temperature performance. In addition, the question of lubricant deterioration during long-term storage was introduced. In order to evaluate the effects of these variables, it was decided that a program for the evaluation and test of various lubricants should be made. These tests were to evaluate lubricants as regards storage life, low and high temperature performance, availability and, lastly, cost. The initial test program was made in two steps. The first consisted of a survey of available lubricants; on the basis of their specifications and the experience of Governmental agencies, an initial selection of oils for test was made. The second step was a series of time-temperature tests using watch movements which had been lubricated with those oils previously selected; in this test a fuze oil (supplied by Frankford Arsenal), a standard commercial watch oil (Stillwatch Oil Co.), and no lubricant ("bare" movement) were evaluated at temperatures of -67°F, -22°F, +73°F, and +150°F. In general, the results of these tests were somewhat clouded by the fact that the watch movements used were discovered to be of poor mechanical quality. In spite of this fact, however, there was a clear indication that, under these conditions, the fuze oil and standard watch oil would not successfully lubricate these movements.

A further investigation of lubricants was conducted in which a wider survey of specifications and published studies were used as a basis. This survey yielded the fact that a special synthetic fuze oil manufactured under Specification MIL-O-11734(ORD) and a watch oil manufactured by Distillation Products, Inc. ("Myvolube "A"), might be acceptable. At this time also the possibility was considered of using a solid lubricant, molybdenum disulfide-in-solvent. A second test series was run in which the redesigned watch movements for the clockwork device were used. Three test batteries were established for this test in order to evaluate the new fuze oil, (commonly known to us as FA#434 from Frankford Arsenal), the "Myvolube A" oil and the molybdenum disulfide lubricant. The results and conclusions from this test are to be found in Appendix E of this report, ADL Interim Report No. 1. In summary, this Interim Report recommended that Myvolube A (re-named about this time as "Convalube A"), should be used in this application. With this lubricant, extreme operating temperature limits of -45°F - +160°F were established.

Subsequent information, arrived after the completion of the entire clockwork problem indicated that the sample of FA#434 oil was either sub-standard or contaminated prior to its delivery to Arthur D. Little, Inc., and, as a result, very probably did not exhibit its best characteristics during this test. While this in no way changes the results obtained with the "Convalube A" lubricant, it very probably could affect a further evaluation of the FA#434 oil might profitably be made for future application in clockwork devices of this type.

Having thus determined the temperature effects on lubrication in the movement, it then remained only to develop some method of protecting the lubricant to the maximum extent possible during long-term storage. While no

Figure 3. L & R Industrial Cleaning Machine, As Used to Clean and Rinse Watch Movements During the lubrication Investigation.

control over the spreading of the lubricant during storage could be exercised, effective control over its oxidation and sludge formation was possible. This was effected by the purging of air from the sealed clockwork mechanism and the introduction of oil-pumped nitrogen gas into the case immediately before final packaging.

F. WATCH MOVEMENT MAINSPRINGS

The original New Haven "dollar" movement makes use of a standard, flat mainspring; this same mainspring was used for the original prototypes of the 24-hour movement in the clockwork delay. Early in the development program, however, the question was raised as to whether or not a mainspring of such ordinary antecedents would be suitable for use in such a specialized device. It was believed that the mainspring might be a potential source of failure in two ways, namely, by breakage or by failure to develop sufficient torque at low temperatures to overcome increased lubricant friction.

In order to resolve these questions, an investigation was initiated to determine whether or not the New Haven mainspring was actually subject to these failures and secondly, whether or not a higher quality mainspring was available. In discussions with both New Haven and Sandvick Steel Company it was learned that the breakage of mainsprings caused by overstressing during their spiral winding usually occurs very soon after the winding operation has been completed. New Haven cited the fact that they normally stored their mainsprings for several months before assembling them into watches, in order to allow this stress cracking and breakage to take place. They further asserted that breakage of mainsprings from this cause after assembly into a watch movement was very uncommon. Sandvick Steel, who supplies mainsprings for watches and clocks of many manufacturers, confirmed this. As a result, this source of failure in the 24-hour movement was discounted.

To determine the effect of rapid temperature change on the mainsprings, and whether or not this would induce their breakage, twenty (20) standard New Haven "dollar" movements were subjected to extremely high rates of temperature change, both above and below room temperature. It was determined from these tests that rapidly decreasing temperatures, in the order of 150°F in one half hour, did not induce breakage, even when the mainsprings were tightly wound. Rapidly increasing temperatures, however, appeared to have somewhat of a more serious effect on these springs; in particular, rapid temperature increase from -65° to approximately +70°F in two hours caused two (2) of the springs to break. The less severe increases, on the order of 70°F - 160°F in two hours, appeared to have little effect and caused no breakage of mainsprings. In view of the fact that these temperature changes to which the mainsprings were subjected in test were far in excess of any expected to be encountered in field service, it was believed that the breakage observed was not excessive and therefore should be tolerated. To correlate the performance of the flat New Haven springs with that of the Sandvick curved-section springs later obtained, however, a similar series of tests were run on these latter springs. The breakage of the curved section Sandvick springs during high rates of temperature change showed no different pattern from that of the New Haven springs. As a result, the question of temperature breakage could not be resolved between these two.

The remaining question regarding mainsprings was that of driving torque delivered at low temperature. Since the movement lubricant would quite naturally undergo an increase in viscosity as the operating temperature was lowered, it was desirable to determine whether or not additional driving torque supplied by the curved section Sandvick springs would be required for this service. In order to evaluate the increase in driving torque available from the Sandvick springs, a battery of 10 New Haven "dollar" watch movements were fitted with this type spring. A series of room temperature tests were run in which this battery of watch movements was compared with a similar battery of movements with standard springs, and the average length of running time of each was recorded. It was found that the curved section mainspring drove these movements on the average of approximately 10% longer than did the flat springs; the available running time of the curved section springs was 36 hours, and that of the flat springs, approximately 33 hours. On the other hand, a series of low temperature tests, using the actual delay mechanism prototypes fitted with the flat springs indicated that failure of the watch movements to run under these conditions could not be attributed to a lack of drive torque. In other words, the standard, flat, New Haven spring appeared sufficiently powerful to drive the mechanism under all anticipated conditions.

In summary, while the curved section spring actually would deliver approximately 10% more driving torque, no other advantage was believed to exist. Since the flat spring was proved adequate for low temperature service and all other conditions were equal, it was finally decided that no change from the original New Haven flat spring would be made.

G. MOVEMENT TIMING AND CALIBRATION

Very early in the clockwork program it was demonstrated that a quick, simple and accurate method of timing the movements would be required. The reading of dials in order to determine running errors did not offer sufficient accuracy for either the initial calibration or the inspection of watch movements during test. Starting with information received from

New Haven Watch and Clock Co., the American Time Products Co., Inc., New York, New York, was contacted to investigate their "Watchmaster" model G-17 timing mechanism. This device consists essentially of a tuning fork which provides a fixed beat signal against which the actual watch mechanism beat is compared. The difference between these beats is recorded as a pattern on a tape. The singular advantage of this instrument is that it provides a readily-available record of the instantaneous beat of the watch mechanism; the results obtained from testing the watch are in the form of an extremely simple tape record. This instrument allowed not only easy testing and determination of the watch beat rate under all test conditions, but also provided a quick and accurate method of evaluating the over-all watch movement quality. In this latter it proved of great value in the detection and elimination of watch movements that were sub-standard for various reasons, such as eccentric gears, burrs and dirt.

The "Watchmaster" timer as shown in Figure 4 was used throughout the test program; during this usage the technique was developed by which the individual watch movements could be quickly calibrated for their final inspection immediately prior to packaging. The technique finally developed was as follows:

a. Wind main spring fully.

b. Allow watch movement to run for four hours.

c. Adjust instantaneous beat rate to between 0 and +1 minute per 24 hours error.

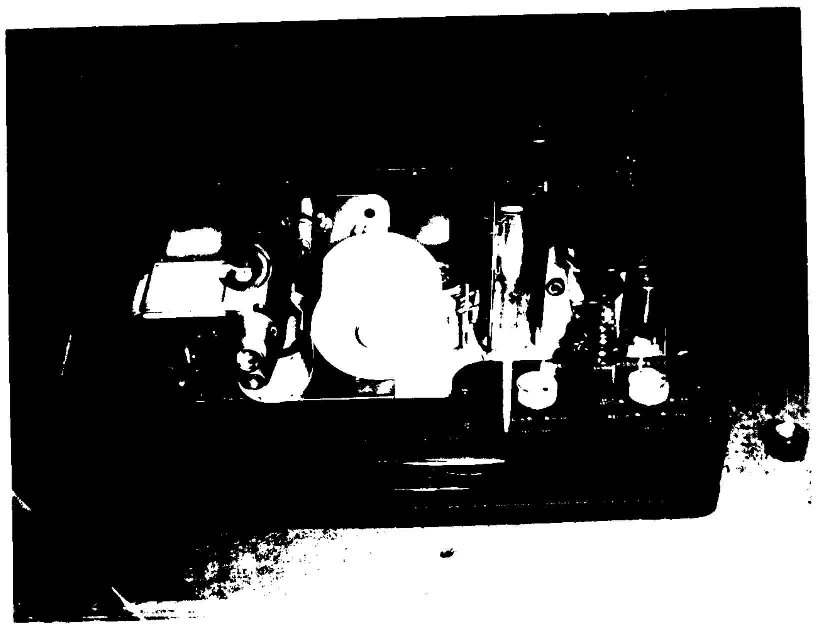

Figure 4. American Time Products, Inc. "Watchmaster", Model G-17 Timer, Used to Record Movement Performance During Tests and Calibrate Movements for Final Inspection.

H. MECHANISM, CASE AND ACCESSORIES

While it had been decided early in the program that the design of the case and mechanism should duplicate those of the original Firing Device, Mark III, there remained several changes which were believed desirable. The source of these changes lie both in previous experience gained with the Firing Device, Mark III and in the Client's desires for a more universal device. The majority of these changes, particularly those to the case, concerned the seals and closures. Minor changes were made to the mechanism and firing linkages in order to reduce the possibility of failure in operation. The largest single change made in the mechanism consisted of the addition of a positive starter to provide a means of giving the movement balance wheel a sharp kick to insure its starting, particularly at low temperatures.

A summary of these changes and the reasons for their being made is as follows:

1. Case

   a. Specified a zinc die casting in place of aluminum for the case; in spite of the increased weight of zinc, the advantages it offered as regards ease of machining (particularly drilling and tapping), increased case die life and better guarantee against the casting porosity, were considered governing.

   b. Altered movement mounting bosses to accept re-designed New Haven movement.

   c. Added pilot hole to provide an out-board bearing for the safety plug when it was in the "safe" position; this was to prevent bending of the plug and stem when the firing pin was released into it during test.

SECRET

d. Enlarged the peep hole in order to increase movement visibility.

e. Altered tripping lever mounts in order to establish tighter tolerance control in the positioning of the tripping lever in relation to the hour movement disc.

f. Altered the external paint and paint specifications; specified parkerizing of the back plate and wash-priming of the zinc die casting in order to hold paint better.

g. Specified painting of the case interior cavity in order to reduce reflection.

h. Reduced the amount of stamped and die cast printing on the case exterior.

2. Seals and Enclosures

a. Replaced the two original back plate caps with one large brass cap.

b. Altered the closure of the back plate cap to make use of an "O"-ring seal.

c. Increased the clearance between the back movement plate cap and winding stem to prevent accidental disturbance of movement time setting when the back plate cap was replaced in operational usage.

d. Changed specifications for gasket; changed material from neoprene to "corprene" and finally to Buna-N, and changed thickness of gaskets from 1/16" to 1/32".

e. Changed original packing gland seals in the positive starter and the safety to include tighter packing for seal against external pressure.

f. Specified the use of Dow-Corning silicone grease No. DC-11 for lubrication and sealing of packing glands.

g. Changed original firing pin hole thread from 3/8" - 26 to 7/16" - 20 in order to mount coupling base primer directly.

h. Specified copper plated Phillips head screws for securing front and back plates; Phillips head screws are easier to set to a predescribed torque with mechanical drive screw drivers.

i. Specified torque settings for all closures.

j. Specified sealing compound (Permatex No. 1) to seal screws and gland adapter threads.

k. Widen slots in both back plate cap and shipping plug to allow use of combat knife or other heavy blade in their removal.

I. FIRING LINKAGE

a. Changed contour of toggle to prevent its binding on the tripping lever foot.

b. Modified shape of the tripping lever to prevent its rubbing against the hour disc.

c. Modified shape of the latch pin and tripping lever pivot and roller to enable better tolerance control of their axial position.

SECRET

d. Changed contour of sear lever to uncover movement peep hole when the firing linkage was cocked.

e. Blued the sear, latch pins and other linkage parts to reduce reflection.

f. Chamfered the leading edge of the firing pin to reduce binding and shaving action within the firing pin bore hole.

g. Specified coating of molybdenum disulfide for lubrication of firing pin and firing pin spring.

J. ACCESSORIES

a. Added positive starter to case.

b. Changed design of the cocking device, including addition of a locking pin.

c. Changed design of the cocking yoke in the positive starter.

d. Altered the M-34 adapter to include longer firing pin stroke and "O"-ring seal.

Additional detail regarding the testing and design for development of the seals and closures is given in Appendix E of this report. Similar details as to the testing and evaluation of the firing linkage and causes for its failure are given in Appendix F.

VII. PRODUCTION HISTORY

A. SPECIFICATIONS

During the development period for the clockwork delay device, but prior to any production, tentative specifications for both the watch movement and the delay mechanism were outlined to reflect both the general design criteria and past experience. The original watch movement specifications were first outlined by Leeds & Northrup Company in a letter of July 30, 1952; these were followed by a second, and somewhat broader set of specifications by Mr. Hiram Keafer, a consultant to Thomaston Special Tool Company, on December 11, 1952. The original specifications for the delay mechanism itself were somewhat more spread out as regards time. The first set received from Leeds and Northrup was dated November 14, 1951; the second, January 11, 1952 and the last set of tentative specifications from them came March 4, 1952.

As previously mentioned, the contents of these specifications were based on the previous experience of both consultants. These various efforts were melded during the early part of 1952 to form the first tentative specifications on which the initial design and first models of the entire clockwork delay assembly were to be constructed.

Quite naturally, it became necessary to make changes in these tentative specifications as time went on as both changes were made to the physical configuration of the device and further experience was gained. During this process of specification, modification, the services of Dr. B. J. Wilson for Leeds & Northrup, Mr. Louis Denegre for New Haven Clock and Watch Company, Mr. Hiram Keafer for Thomaston Special Tool and Messrs. Frank deBishop and W. C. Richtmyer were drawn upon heavily in their respective fields. Cooperation between these people, the Client and Arthur D. Little, Inc. was complete during this period; as a result, although the finalization of these changes was truly a slow process, agreement among those concerned was usually easily made.

The net result of these changes to the specifications for both watch movement and delay mechanism was a set of specifications which were essentially complete by the time final production was initiated. It was not possible, however, to have the final inspection and acceptance procedure well defined by this time, since a large lot of the assembled mechanisms would be required for the testing of the specification procedures in actual practice. The final acceptance procedures were tentatively outlined during the production testing at the Reservation between January and June, 1955. Actual performance of the final specification acceptance testing was accomplished at the Reservation in order to check its workability in practice and, at the same time, develop the unit packaging specifications. While last minute changes were made in the test procedure, no basic alterations of the test criteria were made after January, 1955.

B. MOVEMENT PRODUCTION

The difficulty experienced in locating a manufacturer willing to accept responsibility of producing the watch movements has already been described in a previous section of this report. After the New Haven Clock and Watch Company had been selected as the subcontractor for the watch movements, there was very little difficulty encountered in making known to them and obtaining their agreement for the required changes to the NH "dollar" movements. On December 16, 1952, the discussions with New Haven had proceeded to the point where two hand-made prototypes were ordered; these prototypes were to include all of the changes suggested to date. After much delay in their production, these movements were delivered by New Haven to Thomaston Special Tool Company on June 15, 1953, and were there incorporated in the initial models of the clockwork delay mechanism. The results of tests run on these two prototypes indicated that the general design of both movement and delay mechanisms was satisfactory.

New Haven completed the special tooling required for the watch movement by August 7, 1953. One hundred (100) pilot-run movements were delivered to Thomaston Special Tool by New Haven on September 15, 1953, and there incorporated in the delay mechanisms destined for the first large-scale testing of the device at the Reservation.

During the next 8 months, as the result of both the testing program and further suggestions to meet the desired operating and handling characteristics of the device, there were several changes made in the watch movement and its accessories. These changes are reflected in the previous section of this report, under Watch Design. During this period, New Haven Clock and Watch obtained from J. H. Winn's Sons, of Winchester, Massachusetts, new minute hands to replace the short hands of the original device. They also obtained the services of the Canadian Radium and Uranium Company of New York in the re-finishing and re-striping of the hour dials and drums. Other minor changes were made to the movement at New Haven's facilities. During this period, in spite of the fact that the time consumed was considerably longer than desired, the cooperation given by New Haven personnel was excellent.

By July 31, 1954, all of the details and changes of the watch design had been resolved, and New Haven was given authority to commence production of 1,025 additional units. Final delivery of these units was made during December, 1954. Including the two original prototypes, small pilot lot and the large production, New Haven Clock and Watch produced 1,127 movements under this work order.

C. MECHANISM PRODUCTION

Contact with Thomaston Special Tool Company was originally made on March 24, 1952, as the result of their accidental introduction to the problem through Inghram Watch Company. A final bid was received from them on November 7, 1952, and this bid was accepted by all parties on December 8, 1952. Between the early part of December, 1952 and June 23, 1953 many conferences were held between Thomaston and others concerned with the project regarding design changes to the delay mechanism. These design changes were brought about partially from the experience gained with the original Mark III prototype and partially by the changes made to the watch movement. Thomaston, on June 23, 1953, delivered the first prototypes of the 24-hour clockwork delay mechanism. These prototypes were made from tooling that had not been hardened, so that any changes required in these models could yet be made in the permanent tooling. A meeting on that date by all parties concerned finalized the minor changes believed necessary, and Thomaston was given authority to harden all of the designs.

During the period from June 23, 1953 - August 3, 1953, Thomaston was requested to design and build a prototype of a new positive starter. When completed, this starter was compared to ones submitted by Leeds & Northrup; Thomaston's design, which incorporated fewer parts and appeared to be more rugged, was selected for use in the final mechanism. During this period also Thomaston was requested to revise both the cocking device and the M-34 adapter. By August 3, 1953, all of the designs, including the case, firing linkage and accessories, were believed satisfactory and Thomaston was given authority to proceed immediately in the production of all items.

As with the watch mechanism, there were additional changes made during the final production of the clockwork device. Primary among these changes was the alteration of gaskets and sealing for the clockwork case. These changes are reflected in Appendix E of this report. During this period also Thomaston made many positive suggestions for techniques and procedures to handle production and testing of the device; many of these were incorporated into the final specifications. Final delivery of the last of the mechanisms produced in this final lot were delivered to the Reservation in January, 1955. At that time the packaging, design, and testing of the device was commenced.

VIII. PACKAGING

A. GENERAL PACKAGING CONSIDERATIONS

After final decision had been made as to the components which were to be included in the unit package for the clockwork delay mechanism, a firm basis was then available for the design of both the unit and sub-package units. The components to be included were as follows:

1. Clockwork delay device and its attached winding stem.
2. Small tube of obscuring compound.
3. M-34 detonator.
4. Coupling base primer.
5. Clockwork cocking device.
6. Special adapter for the M-34 detonator.
7. Twelve feet of soft iron wire, for attaching device to target.

The major consideration for incorporating all of these components into a single unit package was that of providing a simple and rugged internal arrangement. In view of the explosive nature of the M-34 detonator and the coupling base primer, this problem of internal arrangement was further complicated by the fact that these items required complete physical protection.

Since a minimum storage life of some 5 to 7 years before surveillance and overhaul was anticipated, it was believed desirable to provide some sort of inert atmosphere within the clockwork case to prevent oxidation of the watch lubrication and corrosion from the entrapped moisture. The relatively long storage requirement also pointed out the fact that elimination of both trapped moisture within the packaging materials and potential sources of container internal corrosion were also desirable.

B. DESIGN OF PACKAGING

The adequate protection of the M-34 detonator and the coupling base adapter were considered to be of primary importance and governed the general package design. The design of their sub-packaging and anchoring within the package proved to be a stumbling block for a considerable time. These problems were finally resolved when it was found that the M-34 detonator could be sub-packaged in a spiral tube and mounted directly on the clockwork case; the extreme dimensions of the clockwork case were greater than that of the detonator sub-package, and hence would prevent damage to the detonator in the event of the cans being crushed. It was also found that the coupling base adapter could be removed to the far side of the unit package from the M-34 detonator and well padded with cushioning material; this reduced the probability that the primer would ever be initiated. In the event of its accidental initiation, however, its physical distance from the M-34 detonator provided assurance that there would be no sympathetic initiation of the M-34.

With adequate protection of the explosive elements thus assured, the remainder of the package design almost automatically fell into place. The use of a spiral-wound mailing tube for packaging of the M-34 detonator was found to be extremely rugged and simple; this method of sub-packaging was immediately extrapolated for use in sub-packaging of the coupling base adapter and cocking device together, as well as providing a firm mounting for the special adapter. Figure 7 shows these components ready for their sub-packaging.

Once the sub-packaging of all components had been determined it was then possible to define the size of the unit package can. George D. Ellis and Sons, Inc. of Philadelphia, Pa. was consulted as a potential supplier of this can. At their suggestion, extra-heavy electroplated tern-plate was specified for the can body, as well as a coating of vinyl resin over the internal tear-strip scores. They also suggested the use of over-sized tear strip keys, in view of the fact that the can material was heavier than normal (0.015"). In addition, pressure testing was specified for each can, in order that there would be 100% insurance against side-and bottom-seam leakage. The exact details of the final tear-strip can and other components specified for the unit package can be obtained from the Drawing 210b-501.

C. UNIT PACKAGING PROCEDURE

Immediately after the final calibration and operational check-out of the clockwork devices the following packaging procedure was initiated:

(a) Several clockwork devices were nested in a vacuum bell jar after their back plate caps and shipping plugs had been loosened. This step is shown in Figure 4.

(b) The bell jar was closed, and the internal pressure was reduced to approximately 24 inches of mercury vacuum. This cycle was extended for 1 minute in order to allow the entrapped air from the clockwork cases to bleed out and be removed. Figure 5 shows the arrangement used for this pump-down operation.

(c) After the delay period at low pressure the vacuum pump was removed from the circuit and nitrogen gas was allowed to bleed slowly back into the bell jar. The devices were allowed to remain in the nitrogen atmosphere for approximately two minutes after it had returned to atmospheric pressure. After that "soaking" period, the back plate caps and shipping plugs were set tight.

(d) The unit package padding and wrapper components were baked dry for approximately 1/2 hour at 250°F to remove all residual moisture. These components are shown in Figure 6.

(e) Sub-packaging was accomplished as shown in Figures 7 and 8. Each sub-packaging component was taped tightly together.

(f) The clockwork delay mechanisms, carrying M-34 detonators and obscuring compound tubes, were then inserted into unit package cans as shown in Figure 8.

(g) The special adapters, coupling base primers, cocking devices and coils of wire were then inserted into the packages as shown in Figure 9.

(h) The packages were then completed by the addition of the top buffer discs, the can tops put in place and immediately double seam sealed as shown in Figures 10 and 11.

A more detailed procedure for the packaging operation is outlined in Section 10, Specification T210b.

Figure 5. Clockwork Delay Mechanisms, as nested in bell jar, ready for purging with nitrogen gas.

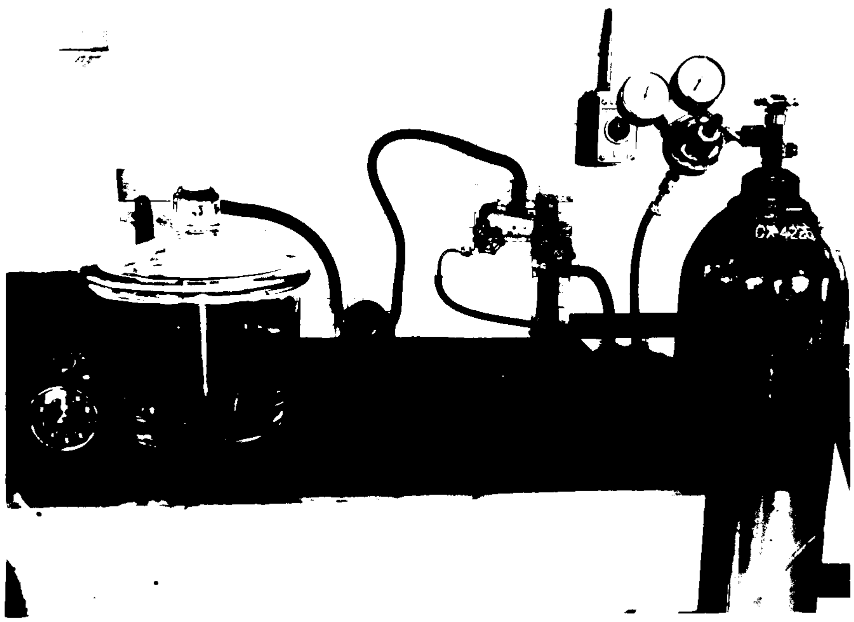

Figure 6. Nitrogen gas purging system used to evacuate air from mechanism cases and introduce nitrogen gas for inert atmosphere packaging. Bell jar at left; altimeter and gas manifold in center; nitrogen regulator and bottle at right.

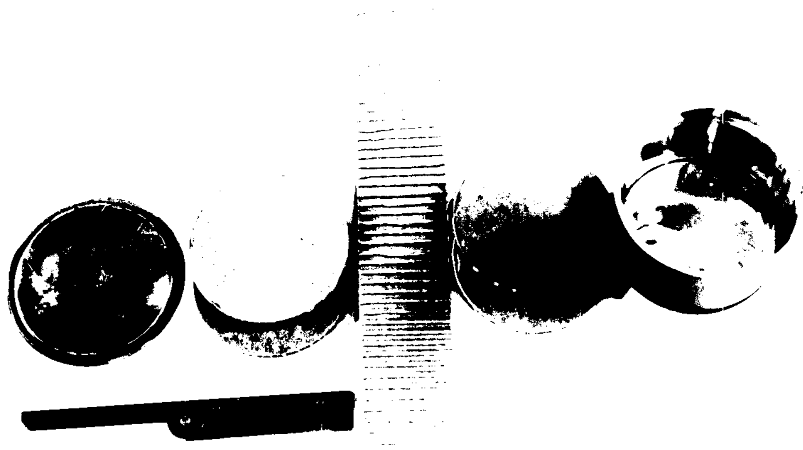

Figure 7. Unit package can, padding and wrapper components. Left, can top; 2nd, two (2) top padding discs; 3rd, can liner; 4th, two (2) bottom padding discs; right, unit package can.

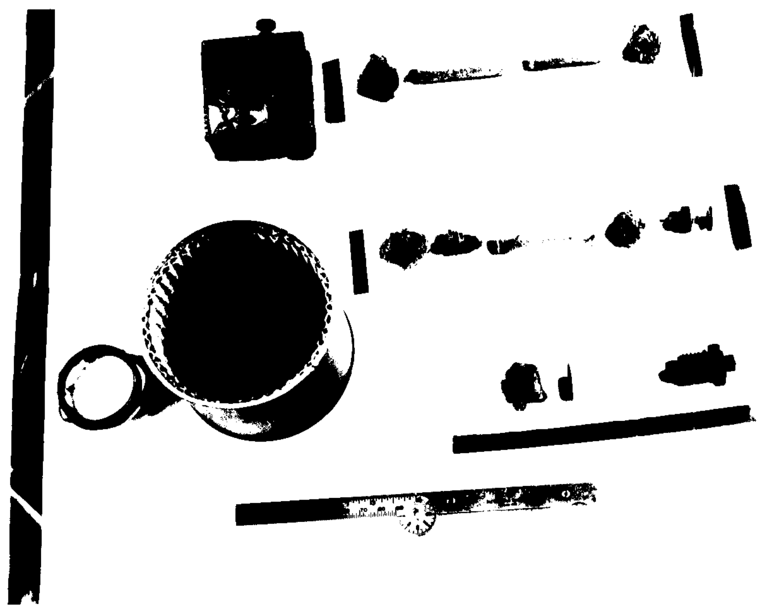

Figure 8. Unit package components, in preparation for sub-packaging. Top left, case, with winding stem and obscuring compound; top right, M-34 detonator, with tube, padding and tape; middle, coupling base adapter and cocking device, with tube, padding and tape. Bottom, special M-34 adapter, with tube, padding and tape. Left, unit package can, with corrugated liner, wire roll and tape.

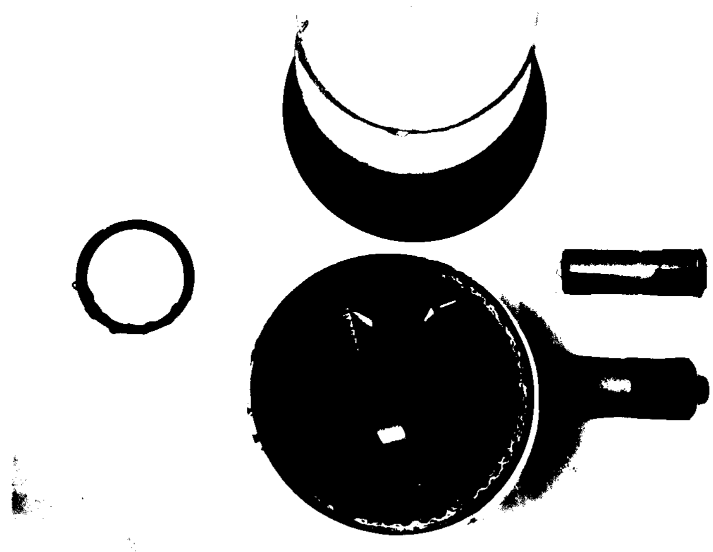

Figure 9. Sub-assembled case, with tube of obscuring compound and M-34 detonator taped in place, as inserted in third packaging step. Case is supported on two corners and start-stop stem to prevent shifting.

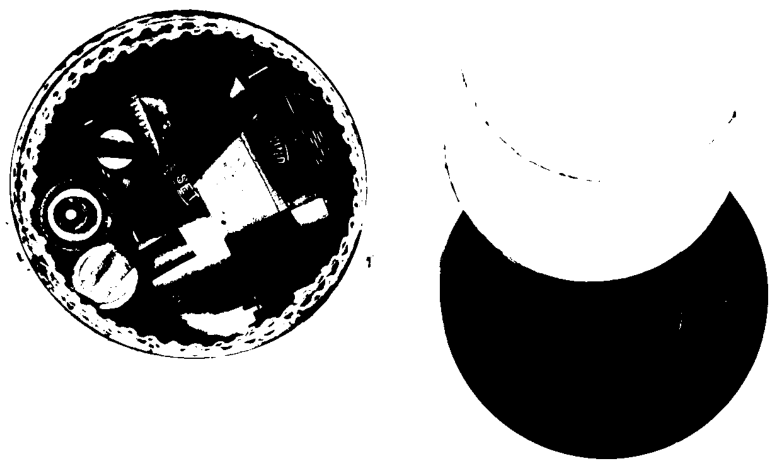

Figure 10. Interior of unit package, with all components in place, ready for insertion of top buffer discs and top closure. This is last step before final closure of the unit package.

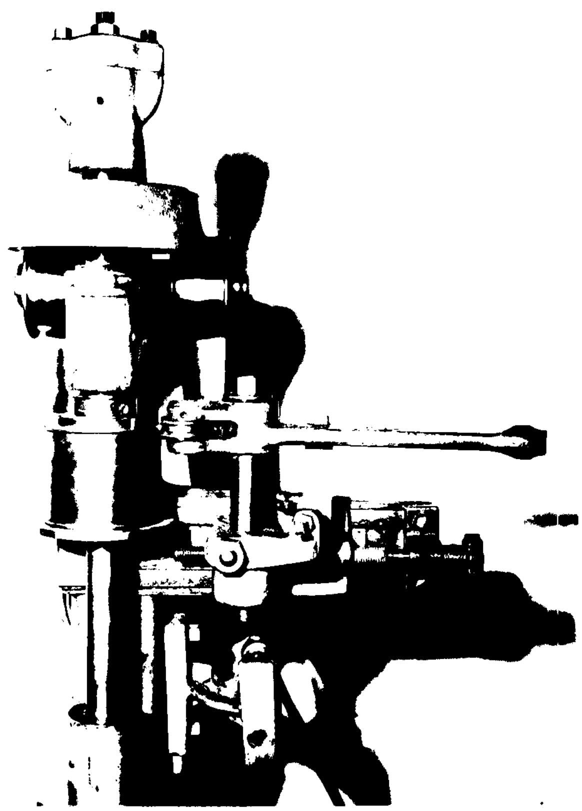

Figure 11. Canning machine, with can ready for final double-seam sealing operation.

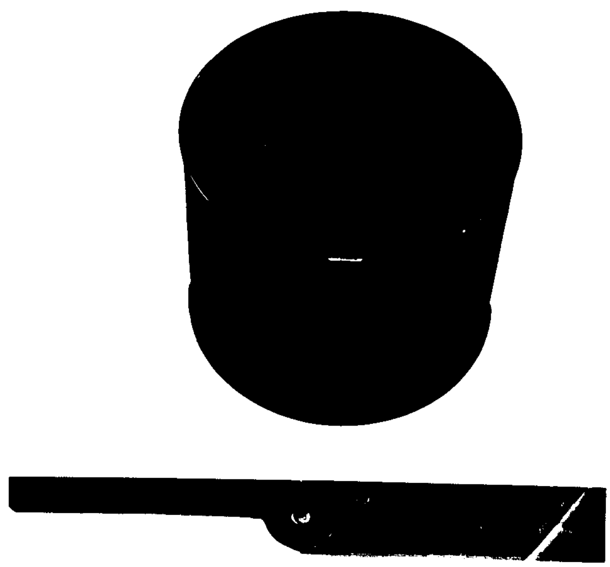

Figure 12. Final unit-package can, as sealed by canning machine.

Specification T210a

1 June 1955

MANUFACTURING, ASSEMBLY, INSPECTION AND PACKAGING SPECIFICATIONS FOR THE 24-HOUR WATCH MOVEMENT AND ITS ACCESSORIES

1. Purpose

1.1 The purpose of this Specification is to insure that the 24-Hour Watch Movement and its accessories are properly manufactured, assembled, inspected and packaged, and will operate in the desired manner.

1.2 The items included under this Specification are as follows:

1.2.1 24-Hour Watch Movement

1.2.2 Hour Disc

1.2.3 Minute Hand

1.2.4 24-Hour Dial

1.2.5 Winding Key and Chain

2. Marking No part of the 24-Hour Watch Movement or its accessories, components, packing and packaging shall carry any trade-marks, names, specification numbers or other means of identification. The Contractor's attention is directed to the fact that some of the specifications cited herein may require certain symbols or markings on the materials. The complete elimination of such markings is required by this Specification, except as noted below:

2.1 The Provisions of Section 2.0 of this Specification shall not apply to packaging labels and other special markings approved by the Contracting Authority.

3. Parts — The 24-Hour Watch Movement and its accessories shall consist of the following parts and assemblies, as described in the below-listed drawings:

	Part Name	Drawing Number
3.1	Final Movement Assembly	210a-101
3.2	Back Movement Plate Assembly	210a-201
3.3	Back Movement Plate	210a-401
3.4	Hairspring Stud	210a-402
3.5	Regulator	210a-403
3.6	Balance Plug Assembly	210a-301
3.7	Balance Plug	210a-404
3.8	Jewel	210a-405
3.9	Barrel Bridge	210a-406
3.10	Pillar Screw	210a-407
3.11	Front Movement Plate Assembly	210a-202
3.12	Front Movement Plate	210a-408
3.13	Click Spring	210a-409
3.14	Click	210a-411
3.15	Click Stud	210a-412
3.16	Pillar, Short	210a-413
3.17	Pillar, Long	210a-414
3.18	Mounting Pillar (Long)	210a-415
3.19	Mounting Pillar (Short)	210a-416
3.20	Retainer, Main Wind Wheel	210a-417

3. Parts cont...............

	Part Name	Drawing Number
3.21	Stud, Dial Wheel	210a-420
3.22	Stud, Hour Wheel Spacer	210a-423
3.23	Balance Screw Assembly	210a-302
3.24	Jewel	210a-405
3.25	Balance Screw	210a-410
3.26	Dial Wheel Assembly	210a-203
3.27	Dial Wheel	210a-418
3.28	Shuck, Dial Wheel	210a-419
3.29	Winding Arbor Assembly	210a-204
3.30	Winding Arbor	210a-421
3.31	Ratchet Wheel	210a-422
3.32	Center Shaft Assembly	210a-205
3.33	Center Shaft	210a-424
3.34	Cannon Pinion	210a-425
3.35	Center Shuck Assembly	210a-206
3.36	Center Wheel	210a-426
3.37	Center Shuck	210a-427
3.38	Washer, Center Friction	210a-428
3.39	Washer, Rotor Pin	210a-429
3.40	Mainspring & Barrel Assembly	210a-207
3.41	Barrel Assembly	210a-303
3.42	Barrel	210a-430

3. Parts cont................

	Part Name	Drawing Number
3.43	Hub, Barrel	210a-431
3.44	Arbor Assembly	210a-304
3.45	Arbor	210a-432
3.46	Arbor Hook, Barrel	210a-433
3.47	Mainspring	210a-434
3.48	Balance Assembly	210a-208
3.49	Balance Wheel Assembly	210a-305
3.50	Wheel Balance	210a-435
3.51	Impulse Pin	210a-436
3.52	Balance Staff	210a-437
3.53	Roller	210a-438
3.54	Collet & Hairspring Assembly	210a-306
3.55	Hairspring	210a-439
3.56	Collet, Hairspring	210a-440
3.57	Wedge, Hairspring	210a-441
3.58	Lever Assembly	210a-209
3.59	Lever	210a-442
3.60	Guard Pin	210a-443
3.61	Escape Pin	210a-444
3.62	Lever Shaft	210a-445

3. Parts Cont..................

	Part Name	Drawing Number
3.63	Escape Pinion Assembly	210a-210
3.64	Escape Pinion	210a-446
3.65	Escape Wheel	210a-447
3.66	4th Wheel Assembly	210a-211
3.67	4th Wheel	210a-448
3.68	4th Pinion	210a-449
3.69	3rd Wheel Assembly	210a-212
3.70	3rd Wheel	210a-450
3.71	3rd Pinion	210a-451
3.72	Washer, Dial Wheel	210a-452
3.73	Hour Disc Assembly	210a-213
3.74	Hour Disc	210a-453
3.75	Hour Socket Assembly	210a-307
3.76	Wheel, Hour Socket	210a-454
3.77	Hour Socket	210a-455
3.78	Washer, Dial	210a-456
3.79	Minute Hand	210a-457
3.80	Nut, Minute Hand	210a-458
3.81	Set Knob	210a-459
3.82	Winding Key Assembly	210a-214

3. Parts Cont................

	Part Name	Drawing Number
3.83	Winding Knob	210a-460
3.84	Key Shaft	210a-461
3.85	Key Chain	210a-462
3.86	Wheel, Main Winding	210a-463
3.87	Shipping Screw	210a-464
3.88	Shipping Nut	210a-465
3.89	24-Hour Dial	210a-466
3.90	Movement Time Train	210a-501
3.91	Movement Packaging Assembly & Details	210a-502

4. Materials

4.1 All materials used in the manufacture of the 24-Hour Watch Movement and its Accessories shall be in strict accordance with those required by the detail drawings listed in Section 3 and the list of packaging materials in Section 10 of this Specification.

4.2 In all cases where an alternate material and/or specification for a material is cited, selection of the material for use shall be made in the order of their listing on the detail drawing applicable. No change from a given material to an alternative material shall be made within a given single contracted order for the 24-Hour Watch Movement and its Accessories after any production of the part in question has been initiated.

5. Finish

5.1 All finishes given and finishing methods used for parts and/or assemblies of the 24-Hour Watch Movement and its Accessories shall be in strict accordance with those required by the detail drawings listed in Section 3 of this Specification.

5.2 No component or assembly of the 24-Hour Watch Movement or its accessories shall be coated or otherwise covered with any type of varnish, shellac, lacquer, plastic or film of any other similar material to prevent oxidation or contamination.

6. Dimensions

6.1 All dimensions shown in the detail drawings listed in Section 3 and the description of packaging in Section 10 of this Specification are cited for the general guidance of the Contractor.

6.2 It is recognized that the exact duplication of the 24-Hour Watch Movements and its Accessories by any but the original manufacturer would be a difficult and costly task. With this point in view, the Contractor, if other than that with whom the original movement and accessory development was done, shall be governed by the following sections:

6.2.1 The movement and accessory dimensions shall be such as to produce an assembled movement and accessories having a general performance and operating characteristic at least equally those defined in Section 8 of this Specification.

6.2.2 The movement and accessory dimensions shall be such as to produce an assembled movement and accessories which will mount on and operate in and with the mechanism case and its related accessories, as outlined in Specifications 210b and 210c.

6.2.3 No limitation shall be placed on the Contractor, other than those cited in this Section, to prevent maximum use of that Contractor's standard parts and assemblies in a movement produced under this Specification.

7. Assembly

7.1 The component parts of the 24-Hour Watch Movements and its accessories shall be assembled in general accordance with Drawing Number 210a-101, Final Movement Assembly, and all other applicable assembly and sub-assembly drawings listed in Section 3 of this Specification.

7.2 It is again recognized that the exact assembly of a watch movement by any but the original manufacturer cannot be completely and individually defined in a general specification of this type. With this point in view, the Contractor, if other than that with whom the original movement and accessory development work was done, shall be governed by the following:

7.2.1 Sections 6.1 and 6.2 shall apply, with the word "assembly" being substituted for the word "dimensions" where applicable.

7.3 In addition to the above Sections of this Specification, the Contractor shall be governed by and responsible for full compliance with the following:

7.3.1 Extreme care shall be exercised during all phases of assembly, inspection and handling to prevent contamination of the movements and their accessories from such sources as dirt, lint, smoke, oil and oil vapor, water and water vapor, perspiration, etc.

7.3.2 After assembly, all movements shall be thoroughly cleaned by immersion and agitation methods to remove contaminants mentioned in the above Section as well as burrs and chips from holes, slots and other recesses.

7.3.3 The use of vapor degreasing as a sole method of cleaning shall be prohibited. The Contractor shall submit an affidavit to the Inspector, prior to the latter's Inspections, that the cleaning methods and solutions used are ones which, under normal cleaning procedures, will completely remove all traces of perspiration contamination.

7.3.4 As an alternative to Section 7.3.3, the Contractor may submit to the Inspector an affidavit to the effect that the following cleaning method and solution have been used for all parts and assemblies:

7.3.4.1 Equipment: Basket-type rotary immersion cleaning machine, similar to L&R Industrial Precision Cleaning machine.

Solution: 3 ounces triethanolamine (tech) in an 8 ounce bottle; add 1 ounce oleic acid (tech) and shake until completely gelled. Add 4 ounces acetone (tech) and blend until homogeneous. Dilute for use with 1 gallon of distilled water.

Procedure: Step 1: Clean, 5-minute agitation.

2: Rinse in distilled water, 3-min. agitation.

3: 1st rinse in naphtha or Stoddard's solvent, 3-minute agitation.

4: 2nd rinse, as above.

5: Clean, oil-free air blast drying, as required to dry completely.

7.3.5 All parts and assemblies shall be handled whenever possible in baskets, and in all cases by personnel wearing clean, oil- and sulfur-free rubber gloves. Assembly tools shall be frequently cleaned to remove oil and other contamination.

7.3.6 No glue, lacquer, cement or other binder shall be used to cement or hold bearing jewels in the assembly.

8. Inspection The following sections describe the nature of and procedures for the Inspection of the 24-Hour Watch Movement and its accessories.

8.1 For purposes of production and Inspection control, a production lot shall be defined as follows:

8.1.1 Movement assemblies: Maximum of 100 movements

Accessories: Maximum of 1000 units each

8.2 The Inspections of the 24-Hour Watch Movement and its Accessories shall consist of the following parts:

8.2.1 A Contractor's Visual Inspection, performed by the Contractor, of all assemblies and accessories prior to their submission to the Inspector in a production lot.

8.2.2 A Contractor's Operating Inspection, performed by the Contractor, on all assembled movements prior to their submission to the Inspector in a production lot.

8.2.3 An Acceptance Inspection, performed by an Inspector or Inspecting Agency designated by the Contracting Authority, on all 24-Hour Watch Movements after their receipt from the Contractor in a production lot.

8.3 During the Inspection periods required by this Specification, the Contractor shall provide the services listed below:

8.3.1 Adequate tools, equipment, gages, and a storage and working area for use by the Inspector in the performance of the Acceptance Inspection required by this Specification.

8.3.2 Access by the Inspector to the Contractor's inspection records and inspection area at all reasonable times during the Inspection periods.

8.4 The Contractor's Visual Inspection shall include the following:

8.4.1 All movements for submission to a production lot shall be inspected under good lighting conditions for the following:

8.4.1.1 There shall be no traces of corrosion, scale, chips and burrs, dirt, lint or fingerprint marks visible under a 2-inch loup (5x magnification).

8.4.1.2 There shall be no over-lubrication of working parts, as defined by good watchmaking practice. In particular, there shall be no oil or other contamination visible on the hairspring coils or in the hairspring regulator slot under a 2-inch loup (5x magnification).

8.4.1.3 With the balance wheel turned to the banked position on both sides, there shall be no clash of the contracted or expanded hairspring coils.

8.4.1.4 The hairspring shall lie flat and true within the limits of good watchmaking practice.

8.4.1.5 All screws and nuts, with the exception of the balance screw and plug, shall be fully tightened; none, including the balance screw and plug, shall show any signs of having been stripped.

8.4.1.6 The train wheels and escapement shall be upright to the front and back plates, the balance screw and plug shall be perpendicular to their respective plates, and the pillars shall be perpendicular to the front and back plates with the limits of detection under a 2-inch loup (5x magnification).

8.4.2 Each 50th accessory item shall be selected from the stock prepared for assembly and, under good lighting conditions, shall be inspected for the following:

8.4.2.1 Proper size and configuration of components and proper sequence of assembly.

8.4.2.2 Absence of deformation or deterioration.

8.4.2.3 Absence of any indication that the units have been mishandled or contaminated.

8.5 The Contractor's Operating Inspection shall consist of the following:

8.5.1 All movements for submission to a production lot, having been passed by the Contractor's Visual Inspection, shall be closely inspected for the following operating characteristics:

8.5.1.1 The center friction clutch shall slip smoothly and uniformly when a torque of fifty (50) to one hundred (100) gram-centimeters is applied at an ambient test temperature of 68 to 78 Deg. F.

8.5.1.2 With the mainspring wound three quarters (3/4) turn, the movement on edge with balance wheel in the top position, the movement shall start nine (9) times out of ten (10) attempts at an ambient test temperature of 68 to 78 Deg. F.

8.5.1.3 With the mainspring wound one (1) turn and the movement as in Section 8.5.1.2, the movement shall start ten (10) times out of ten (10) attempts.

8.5.1.4 The balance wheel motion shall equal or exceed the following standards when the movement is run at an ambient test temperature of 68 to 78 Deg. F. and the movement dial down:

Mainspring Wind	Balance Wheel Motion
One (1) turn down	Not less that $1\frac{1}{4}$ turns or more than 1 3/4 turns; no over-hanging in any case.
After 24-hour run	Not less than 3/4 turn.

8.5.1.5 The Movement shall be capable of being regulated to a cumulative error of not more than three (3) minutes in twenty-four (24) hours when the movement is run in the dial-down position at an ambient test temperature of 68 to 78 Deg. F.

8.5.1.6 The movement shall run continuously and smoothly for at least thirty (30) hours without rewinding of the mainspring, when the movement is in the dial-down position at an ambient test temperature of 68 to 78 Deg. F.

8.5.1.7 The mainspring click action shall allow at least five (5) degrees backlash, and the click action shall be free-moving when the mainspring tension has been removed.

8.6 The Acceptance Inspection shall consist of the following:

8.6.1 All movements for submission to the Inspector as a production lot shall be prepared by the Contractor as follows:

8.6.1.1 The movements shall have been run continuously for at least twenty-four (24) hours immediately prior to their submission for the Acceptance Inspection.

8.6.1.2 The movements shall be running, although they may not be fully wound, at the time of their submission for the Acceptance Inspection.

8.6.2 The timing test for the Acceptance Inspection shall be as follows:

8.6.2.1 The movements in the production batch shall be fully wound and run for twenty-four (24) hours in the dial-down position at an ambient test temperature of 68 to 78 Deg. F.

8.6.2.2 All movements so tested shall show a cumulative error or not more than plus or minus three (3) minutes in twenty-four (24) hours, when referred to true time.

8.6.2.3 All movements shall continue running smoothly for at least thirty (30) hours. This run, from the twenty-four (24) hour time to the thirty (30) hour maximum, may be made in any position at an ambient test temperature of 68 to 78 Deg. F.

9. Acceptance and Rejection Standards

9.1 The Contractor's Visual Inspection shall be accepted by the Inspector upon receipt from the Contractor of an affidavit stating that the 24-Hour Watch Movements and its Accessories have been inspected in accordance with and meet the requirements of Section 8.4 of this Specification.

9.2 The Contractor's Operating Inspection shall be accepted by the Inspector upon receipt from the Contractor of an affidavit stating that the 24-Hour Watch Movements in the production lot have been inspected in accordance with and meet the requirements of Section 8.5 of this Specification.

9.3 The Acceptance Inspection

9.3.1 Acceptance of the production lot of 24-Hour Watch Movements shall be made by the Inspector if all movements in the lot meet the requirements of Section 8.6 of this specification.

9.3.2 Tentative rejection of the entire production lot shall be made by the Inspector if no more than five (5) of the Movements in the lot are rejected under Section 8.6 of this Specification.

9.3.2.1 In the event of a tentative rejection of the production lot, the Contractor may, at his own discretion, provide substitute movements to take the place of those rejected. The substitute movements shall be inspected and accepted by the Inspector in accordance with Section 8.6 of this Specification prior to their being incorporated into the production lot.

9.3.2.2 Upon satisfactory substitution of movements under Section 9.3.2.1 of this Specification, the Inspector shall make acceptance of the production lot.

9.3.3 Rejection of the entire production lot shall be made by the Inspector when six (6) or more of the movements in the lot have been rejected under Section 8.6 of this Specification. No tentative rejection of the lot shall be allowed in this case.

9.4 <u>Scrapping, Reworking, Salvage and Re-Submission to Inspection.</u>

9.4.1 Individual 24-Hour Watch Movements rejected from a production lot and all of the movements rejected from a lot under Section 9.3.3 of this Specification shall be returned to the Contractor for his disposal.

9.4.2 The Contractor may, at his own discretion and expense, completely re-inspect the movements so rejected from a production lot under Section 9.3.3 of this Specification, and then resubmit the acceptable movements for an Acceptance Inspection in a new lot.

9.4.3 Under this Specification, the Contractor shall be permitted, at his own discretion and expense, to scrap, rework, readjust or salvage any or all of the movements or their components which have been rejected by the Inspector under Section 9.3 of this Specification.

10. Packaging The 24-Hour Watch Movement and its accessories shall be unit- and gross packaged, as outlined in the following sections, to prevent damage and deterioration during handling, storage and transit.

10.1 The Unit Packaging shall be as follows:

10.1.1 The Movement Unit Package shall be in general accordance with the Movement Packaging Assembly and Details, Drawing Number T210a-502, of this Specification.

10.1.2 The 24-Hour Dial Unit Package shall consist of individual paper envelopes for each dial.

10.1.3 The Winding Key and Chain shall not be unit packaged.

10.2 The Gross Packaging shall be as follows:

10.2.1 The Movement Gross Package shall consist of unit packages packed for storage and transit in accordance with the best standards of watchmakers' shipping practices.

10.2.2 The 24-Hour Dial Gross Package shall consist of unit package envelopes stacked edgewise in lots of approximately two hundred (200) within a suitable gross container made of at least 1/8" 200-pound test double faced corrugated fiberboard having a 4-flap closure. The unit packages shall be cushioned and held within the gross package so that there will be no rattle or shifting of the envelopes. The gross package closure shall be sealed with either glue or tape to prevent accidental opening during handling and transit.

10.2.3 The Winding Stem and Chain Gross Package shall consist of loose lots of approximately five hundred (500) units in a suitable outer container. The units shall be cushioned within the container to prevent rattling and shifting. The container closure shall be sealed with either glue or tape to prevent accidental opening during handling and transit.

10.2.4 The total number of units in each gross package shall be plainly marked on the closure of each package. No other marking or means of identification, other than that approved by the Contracting Authority, shall be made on the containers.

Specification T210c-1
1 June, 1955.

MANUFACTURING, ASSEMBLY, INSPECTION AND PACKAGING SPECIFICATIONS FOR THE SPECIAL ADAPTER

1. Purpose — The purpose of this Specification is to insure that the Special Adapter is properly manufactured, assembled, inspected and packaged, and will operate in the desired manner.

2. Marking — No part of the Special Adapter or any of its components, packing or packaging shall carry any trademarks, names, specification numbers or other means of identification. The Contractor's attention is directed to the fact that some of the specifications cited herein may require certain symbols or markings on the materials. The complete elimination of such markings is required by this Specification, except as noted below:

2.1 The provisions of Section 2.0 of this Specification shall not apply to the following:

2.1.1 Packaging labels and other special markings approved by the Contracting Authority.

2.1.2 Color-code spots molded into the "O"-ring seal material, Part No. 210c-407.

3. Parts — The Special Adapter shall consist of the following parts and assemblies, as described in the below-listed drawings:

	Qty	Part Name	Drawing Number
3.1	1	Striker Pin	210c-401
3.2	1	Adapter Body	210c-402
3.3	1	Spring	210c-403
3.4	1	Retainer	210c-404
3.5	1	Snap Washer	210c-405
3.6	1	Washer, large	210c-406
3.7	1	Seal, "O"-ring	210c-407

3.8	1	Washer, small	210c-408
3.9		Adapter Assembly	210c-101

4. Materials — All materials used in the manufacture and packaging of the Special Adapter shall be in strict accordance with those required by the detail drawings listed in Section 3 and the list of packaging materials in Section 10 of this Specification.

5. Finish — All finishes given and finishing methods used for parts and/or assemblies of the Special Adapter shall be in strict accordance with those required by the detail drawings listed in Section 3 of this Specification.

6. Dimensions — All dimensions of the components, assemblies, packing and packaging of the Special Adapter shall be in strict accordance with those required by the detailed drawings listed in Section 3 and the description of packaging in Section 10 of this Specification.

7. Assembly

7.1 The component parts of the Special Adapter shall be assembled in strict accordance with the Adapter Assembly, Drawing Number 210c-101 of this Specification; the packaging assembly shall be in accordance with the packaging assembly methods described in Section 10 of this Specification.

7.2 All metal components of the Special Adapter shall be thoroughly cleaned prior to assembly with a liquid, non-corrosive solvent, to remove all grease, dirt and loose chips.

8. Inspection — The following Sections describe the nature of and procedures for the Inspections of the Special Adapter.

8.1 For purposes of production and Inspection control, a production lot shall be one thousand (1000) assembled but unpackaged Special Adapters.

8.2 The Inspections of the Special Adapter shall consist of the following parts:

8.2.1 A Contractor's Inspection, performed by the Contractor after the assembly of the Special Adapters but prior to their submission to the Inspector in a production lot.

8.2.2 An Acceptance Inspection, performed by an Inspector or Inspecting Agency designated by the Contracting Authority.

8.3 During the Inspection periods required by this Specification, the Contractor shall provide the services listed below:

8.3.1 Adequate tools, equipment, gages and a storage and working area for use by the Inspector in the performance of the Acceptance Inspection required by this Specification.

8.3.2 Access by the Inspector to the Contractor's inspection records and inspection area at all reasonable times during the Inspection periods.

8.4 The Inspection procedures shall be as follows:

8.4.1 The Contractor's Inspection shall include the following:

8.4.1.1 Each assembled Special Adapter shall be visually inspected to insure the absence of broken, burred or bent threads on the Adapter Body. (Part No. 210c-402.)

8.4.1.2 Each assembled Special Adapter shall be functionally inspected by pushing the Striker Pin (Part No. 210c-401) through its entire travel and allowing it to return to its normal position under the force of only the Spring (Part No. 210c-403), to insure the complete absence of binding and/or galling of the Striker Pin within the Adapter Body.

8.4.2 The Acceptance Inspection shall include the following:

8.4.2.1 Beginning with any Special Adapter of his selection, the Inspector shall cause each 20th assembled Special Adapter in the production lot to be subjected to the inspections listed below:

8.4.2.2 Presence of components and proper sequence of their assembly, in accordance with the Adapter Assembly, Drawing Number 210c-101, of this Specification.

8.4.2.3 Adequate preservation and finishing of components.

8.4.2.4 Proper dimensional tolerances and pitch of each Adapter Body screw thread, as determined by suitable screw thread gages.

8.4.2.5 Absence of burrs, loose chips, heavy gouges or other malformations in or on the Special Adapter.

8.4.2.6 Absence of binding and/or galling of the Striker Pin throughout its entire travel within the Adapter Body.

9. Acceptance and Rejection Standards

9.1 The Contractor's Inspection shall be accepted by the Inspector upon receipt from the Contractor of an affidavit stating that the Special Adapters in a production lot have been inspected in accordance with and meet the requirements of Section 8.4.1 of this Specification.

9.2 The Acceptance Inspection

9.2.1 Acceptance of the Special Adapters in a production lot shall be made by the Inspector if no more than two (2) Special Adapters in the lot have been rejected for any of the reasons listed in

Section 8.4.2 of this Specification.

9.2.2 Rejection of the entire production lot shall be made by the Inspector if three (3) or more Special Adapters in the lot have been rejected for any of the reasons listed in Section 8.4.2 of this Specification.

9.3 Scrapping, Reworking, Salvage and Re-Submission to Inspection

9.3.1 Individual Special Adapters rejected from a production lot, and all of the Special Adapters in lots rejected by the Inspector shall be returned to the Contractor for his disposal.

9.3.2 The Contractor may, at his own expense, completely re-inspect a production lot rejected under Section 8.4.2 of this Specification, and then resubmit the acceptable Special Adapters for an Acceptance Inspection as a new production lot.

9.3.3 Under this Specification, the Contractor shall be permitted, at his own discretion and expense, to scrap, rework or salvage any or all of the Special Adapters or their components which have been rejected by the Inspector under Section 8.4.2 of this Specification.

9.4 Inspection and Disposition of Scrap

9.4.1 In the event that the Contractor elects to scrap Special Adapters and/or their components under Section 9.3.3 of this Specification, he shall render all components and assemblies so scrapped totally unidentifiable by melting.

9.4.2 The Contractor shall not dispose of such melted scrap until it has been inspected by the Inspector and the latter's written permission obtained for the disposal.

10. Packaging The Special Adapter shall be sub- and gross-packaged, as outlined in the following sections, to prevent damage and deterioration during handling, storage and transit.

10.1 Sub-Packaging of the Special Adapter, which is intended for direct insertion into the ultimate package, shall be accomplished as follows:

10.1.1 The Sub-Package materials shall be as follows:

10.1.1.1	Tube, paper, mailing	PPP-T-495
10.1.1.2	Cushioning material, cellulosic	UU-C-843
10.1.1.3	Tape, adhesive, pressure-sensitive	JAN-P-127

10.1.2 The Sub-Package components shall consist of the following:

10.1.2.1 The tube, paper, mailing, shall be round, spiral-wound, size 7/8" I.D. x 1-3/4" long, in accordance with Federal Specification PPP-T-495.

10.1.2.2 The cushioning material, cellulosic, non-hygroscopic, medium-density, may be in roll form, approximately 1/16" to 1/8" nominal thickness, in accordance with Federal Specification UU-C-843, Type III, Class B.

10.1.2.3 The tape, adhesive, pressure-sensitive, shall be size 1/2" x 3", color black, in accordance with Specification JAN-P-127.

10.1.3 The Sub-Packaging method shall be as follows:

10.1.3.1 One (1) inspected Special Adapter shall be inserted with its large end (1/2"-24 BSF threaded end) down into one (1) mailing tube.

10.1.3.2 One (1) piece of adhesive tape shall be placed around the neck of the mailing tube so that it adhered equally to the tube neck and the hexagonal shoulder of the Special Adapter, holding the latter firmly in the tube.

10.1.3.3 The void remaining within the tube, under the Special Adapter, shall then be tamped with cushioning material. The cushioning material shall be tamped in place so that it will remain firmly in position in the tube, preventing any downward movement of the Special Adapter Striker Pin.

10.2 The Gross Packaging of the Special Adapter by the Contractor represents only an interim stage, designed to provide adequate protection against damage and deterioration during handling, storage and transit. As it does not represent the final gross packaging of the Special Adapter, the Contractor shall be required to meet only the following general requirements as regards the gross packaging of the Special Adapters.

10.2.1 The Special Adapters accepted by the Inspector shall be gross packaged in lots of more than two hundred (200) nor less than fifty (50) sub-packaged units.

10.2.2 The Special Adapters shall be gross packaged by stacking them on end, with the open tube-end downward, in rows within the gross container. Adequate protection of one layer from the next shall be provided by separators of at least 1/8" double-faced corrugated fiberboard.

10.2.3 The outer gross container shall be made of at least 1/8" thick 200 pound test double-faced corrugated fiberboard, and shall have taped or stapled seams and a 4-flap top closure.

10.2.4 The final closure of the packages shall be made with tape, either gummed paper or adhesive, at least 3" wide, placed completely over the top closure and any open seams.

10.2.5 The total number of units in each package shall be plainly marked on the top closure. No other marking or means of identification, other than that approved by the Contracting Authority, shall be made on the container.

MANUFACTURING, ASSEMBLY, INSPECTION AND PACKAGING SPECIFICATIONS FOR THE COCKING DEVICE

1. Purpose — The purpose of this Specification is to insure that the Cocking Device is properly manufactured, assembled, inspected and packaged, and will operate in the desired manner.

2. Marking — No part of the Cocking Device or any of its components, packing or packaging shall carry any trademarks, names, specification numbers or other means of identification. The Contractor's attention is directed to the fact that some of the specifications cited herein may require certain symbols or markings on the materials. The complete elimination of such markings is required by this Specification, except as noted below.

2.1 The provisions of Section 2.0 of this Specification shall not apply to packaging labels and other special markings approved by the Contracting Authority.

3. Parts — The Cocking Device shall consist of the following parts and assemblies, as described in the below-listed drawings:

	Qty	Part Name	Drawing Number
3.1	1	Plug	210c-409
3.2	1	Cap	210c-410
3.3	1	Spindle	210c-411
3.4	1	Pin	210c-412
3.5		Cocking Device Assembly	210c-102

4. Materials — All materials used in the manufacture and packaging of the Cocking Device shall be in strict accordance with those required by the detail drawings listed in Section 3 and the list of packaging materials in Section 10 of this specification.

5. **Finish** All finishes given and finishing methods used for parts and/or assemblies of the Cocking Device shall be in strict accordance with those required by the detail drawings listed in Section 3 of this Specification.

6. **Dimensions** All dimensions of the components, assemblies, packing and packaging of the Cocking Device shall be in strict accordance with those required by the detail drawings listed in Section 3 and the description of packaging in Section 10 of this Specification.

7. **Assembly**

7.1 The component parts of the Cocking Device shall be assembled in strict accordance with the requirements of the Cocking Device Assembly, Drawing Number 210c-102, of this Specification; the packaging assembly shall be in accordance with the packaging assembly methods described in Section 10 of this Specification.

7.2 All metal components of the Cocking Device shall be thoroughly cleaned, either prior to or after assembly, with a liquid, non-corrosive solvent to remove all grease, dirt and loose chips.

8. **Inspection** The following sections describe the nature of and procedures for the Inspection of the Cocking Device.

8.1 For purposes of production and Inspection control, a production lot shall be one thousand (1000) assembled but unpackaged Cocking Devices.

8.2 The Inspection of the Cocking Devices shall consist of a final Acceptance Inspection, performed by an Inspector or Inspecting Agency designated by the Contracting Authority.

8.3 During the Inspection periods required by this Specification, the contractor shall provide the services listed below:

8.3.1 Adequate tools, equipment, gages, and a storage and working area for use by the Inspector in the performance of the Acceptance Inspection required by this Specification.

8.3.2 Access by the Inspector to the Contractor's inspection records, if any, and the latter's inspection area at all reasonable times during the Inspection periods.

8.4 The Acceptance Inspection procedure shall be as follows:

8.4.1 Beginning with any Cocking Device of his selection, the Inspector shall cause each 50th assembled Cocking Device in the production lot to be subjected to the inspections listed below:

8.4.1.1 Presence of components and proper sequence of their assembly, in accordance with the Cocking Device Assembly, Drawing Number T210c-102, of this Specification.

8.4.1.2 Adequate preservation and finishing of components.

8.4.1.3 Proper dimensional tolerance and pitch of the Plug (Part No. T210c-409) screw threads, as determined by suitable screw thread gages.

8.4.1.4 Absence of burrs, loose chips, heavy gouges or other malformations in or on the Cocking Device.

8.4.1.5 Freedom of movement of the Spindle (Part No. T210c-411) within the Plug.

8.4.1.6 Absence of movement of the Cap (Part No. T210c-410) on the Spindle under normal finger pressure.

9. Acceptance and Rejection Standards

9.1 Acceptance of the Cocking Devices in a production lot shall be made by the Inspector if no more than one (1) of the Cocking Devices in the lot has been rejected for any of the reasons listed under Section 8.4 of this Specification.

9.2 Rejection of the entire production lot shall be made by the Inspector if two (2) or more of the Cocking Devices in the lot have been rejected for any of the reasons listed under Section 8.4 of this Specification.

9.3 Individual Cocking Devices rejected from a production lot, and all of the Cocking Devices in lots rejected by the Inspector shall be returned to the Contractor for his disposal.

9.4 The Contractor may, at his own expense, completely re-inspect a production lot rejected under Section 8.4 of this Specification, and then re-submit the acceptable Cocking Devices for an Acceptance Inspection as a new production lot.

9.5 Under this Specification, the Contractor shall be permitted, at his own discretion and expense, to scrap, rework or salvage any or all of the Cocking Devices or their components which have been rejected by the Inspector under Section 8.4 of this Specification.

9.6 <u>Inspection and Disposition of Scrap</u>

9.6.1 In the event that the Contractor elects to scrap Cocking Devices and/or their components under Section 9.5 of this Specification, he shall render all components and assemblies so scrapped totally unidentifiable by melting.

9.6.2 The Contractor shall not dispose of such melted scrap until, it has been inspected by the Inspector, and the latter's written permission obtained for the disposal.

10. Packaging — As the packaging of the Cocking Devices by the Contractor represents only an interim stage and is designed to provide protection against deterioration and damage during storage and transit, the Contractor shall be required to meet only the following general requirements as regards the packaging of the Cocking Device.

10.1 The Cocking Devices accepted by the Inspector shall be packaged in lots of not more than five hundred (500) nor less than one hundred (100) assembled units.

10.2 The Cocking Devices may be loose packaged, without cushioning or buffer material around the individual units.

10.3 Each package shall be made of 200-pound test double-faced, corrugated fiberboard, at least 1/8" thick, having taped or stapled seams and a 4-flap top closure.

10.4 Final closure of the packages shall be made with tape, either gummed paper or adhesive, at least 3" wide, placed completely over the top closure and any open seams.

10.5 The total number of units in each package shall be plainly marked on the top closure. No other marking or means of identification, other than that approved by the Contracting Authority, shall be made on the container.

Specification T210C 3
30 June 1955

MANUFACTURING, INSPECTION AND PACKAGING SPECIFICATIONS FOR THE OBSCURING COMPOUND

1. Purpose

The purpose of this Specification is to insure that the Obscuring Compound is properly manufactured, inspected and packaged and will perform in the desired manner.

2. Marking

No part of the Obscuring Compound packaging or packing shall carry any trademarks, names, specification numbers or other means of identification. The Contractor's attention is directed to the fact that some of the Specifications cited herein may require certain symbols or markings on the materials. The complete elimination of such markings is required by this Specification.

3. Parts

The Obscuring Compound has no parts or drawings.

4. Materials

The materials used in the manufacture and packaging of the Obscuring Compound shall be in strict accordance with those listed below and in Section 10 of this Specification.

4.1 Adhesive: Cellulose acetate base cement, similar to General Electric Co. "Glyptal No. 1276."

4.2 Pigment: Carbon black, dry, paint pigment type, Spec. TT-C-120 (1) or lamp black, dry, paint pigment type, Spec. TT-L-70.

4.3 Solvent: Ethyl acetate, Spec. O-A-51b.

5. Finish

Not applicable to this Specification.

6. Dimensions

All dimensions of the packing and packaging of the Obscuring Compound shall be in strict accordance with those required in Section 10 of this Specification.

7. Mixing

The materials listed above in Section 4 of this Specification shall be mixed in the following manner:

7.1 Three (3) parts by volume of the adhesive and three (3) parts by volume of the solvent shall be blended until the mixture is uniformly mixed and smooth in consistency.

7.2 One (1) part by volume of the pigment shall then be blended into the adhesive-solvent mixture. The pigment shall be thoroughly dispersed in the mixture by mixing.

8. Inspection

The following Sections describe the nature of and procedures for the Inspection for each batch of the Obscuring Compound. In general, it should be stated that the Inspection is intended to establish the general suitability of the Compound for its intended use, rather than to exercise strict acceptance or rejection standards. With this viewpoint in mind, corrective measures are suggested and allowed by this Specification for use in bringing each batch of the Compound to a generally acceptable performance standard.

8.1 The Inspection of the Compound shall consist of three (3) parts, namely:

8.1.1 Viscosity test: to insure that the viscosity of the Compound is within generally acceptable viscosity limits.

8.1.2 Drying test: to insure that the Compound will tack and dry within a nominal time limit.

8.1.3 Opacity test: to insure that the Compound will adequately limit observation and legibility of printed matter.

8.2 The Inspection Procedures shall be as follows:

8.2.1 The viscosity test shall be conducted at a room temperature of between 70 F and 80 F; the Obscuring Compound and test surfaces shall have been stabilized within these temperatures for at least 12 hours prior to the test. The test shall consist of the following:

8.2.1.1 Approximately one half (1/2) fluid ounce of the Obscuring Compound shall be applied from a metallic collapsible tube to the surface of a 2-1/2" x 2-3/4" polished, optical grade acrylic sheet (Plexiglas). The tube nozzle may be used to smear the Compound over the entire surface of the test sheet.

8.2.1.2 The test sheet shall be turned to a vertical position immediately after the compound coating has been applied.

8.2.2 The drying test shall be a direct continuation of the viscosity test, and the test times shall be measured from the time the test sheet is turned to a vertical position. (No forced air circulation shall be used to induce tacking or drying.)

8.2.3 The opacity test shall be a direct continuation of the previous tests, but may be conducted at any time after the drying has been completed. A segment of printed text from any newspaper shall be applied directly to the uncoated side of the test sheet.

9. Acceptance and Rejection Standards

9.1 The viscosity test results shall be considered acceptable when and if:

9.1.1 The Obscuring Compound covers the test sheet without voids or non-wetted spots.

9.1.2 The Obscuring Compound does not flow from the test sheet when the latter is turned to a vertical position.

9.2 The drying test results shall be considered acceptable when and if:

9.2.1 The Obscuring Compound tacks completely after a time duration of five (5) minutes.

9.2.2 There are no liquid bubbles remaining in the coating after twenty (20) minutes.

9.3 The opacity test results shall be considered acceptable when and if:

9.3.1 The test shall be illegible when viewed through the coating under direct face illumination of a 100-watt incandescent or a 20-watt fluorescent bulb from a distance of two (2) feet.

9.4 Should a lot or batch of the Compound fail to meet any of the above individual test requirements, the following corrective actions may be employed to bring its performance within acceptance limits for all tests.

9.4.1 Viscosity: the adhesive content may be altered by any amount to achieve the required flow properties.

9.4.2 Drying: the solvent content may be altered by any amount to achieve the required drying properties.

9.4.3 Opacity: the pigment content may be increased to achieve the required obscuring density. The pigment content shall not be decreased below the limits established in Section 7.2 of this Specification.

9.4.4 In the event that any lot or batch mixture is altered from that cited in Section 7.2 of this Specification, it shall be re-inspected after alteration to establish conformity of the new mixture with the performance acceptance standards cited in Section 8.2.

10. Packing and Packaging

10.1 Unit Packaging

10.1.1 The Obscuring Compound shall be unit packaged in standard commercial collapsible tubes of size 1/2" OD x 2" long, having a "break-off" nozzle. The tube material shall be of a standard commercially available lead-antimony alloy.

10.1.2 The tubes shall be filled half-full with the Obscuring Compound.

10.1.3 The tubes shall then be collapsed to eliminate air pockets and sealed. A standard quadruple-fold seal closure shall be used.

10.2 Gross Packaging of the Obscuring Compound is intended to provide only nominal protection for the filled tubes during their temporary storage awaiting final packaging as a component or a larger assembly.
In view of this temporary nature of this gross packaging, the tubes shall be packaged as follows:

10.2.1 Each gross package shall consist of the original sectionalized box used to protect the unfilled tubes.

10.2.2 Tubes shall be placed tip-downward in the sections.

Specification 210b
1 June 1955

MANUFACTURING, ASSEMBLY, ADJUSTMENT, INSPECTION AND PACKAGING SPECIFICATIONS FOR THE 24-HOUR CLOCKWORK DELAY MECHANISM

1. Purpose — The purpose of this Specification is to insure that the 24-Hour Clockwork Delay Mechanism is properly manufactured, assembled, adjusted, inspected and packaged, and will operate in the desired manner.

2. Marking — No part of the Mechanism or its components, packing or packaging shall carry any trademarks, names, specification numbers or other means of identification. The Contractor's attention is directed to the fact that some of the specifications cited herein require the use of certain markings and symbols on the materials. The complete elimination of such markings is required by this Specification, except as noted below:

2.1 The provisions of Section 2.0 of this Specification shall not apply to the following:

2.1.1 Packaging labels and other special markings authorized by the Contracting Authority.

2.1.2 Color code marks molded into the O-ring seal material for the Cap Gasket, Dwg. 210b-436

3. Parts — The Mechanism shall consist of the following parts and assemblies, as described in the below listed drawings:

	Part Name and Description	Drawing Number
3.1	Start-Stop Screw Assembly	210b-201
3.2	Shaft	210b-401

3. <u>Parts</u> cont..........

	Part Name and Description	Drawing Number
3.3	Snap Washer	210b-402
3.4	Packing	210b-403
3.5	Washer	210b-404
3.6	Adapter	210b-405
3.7	Packing Nut	210b-406
3.8	Knob	210b-407
3.9	Washer, Stop	210b_449
3.10	Rivet	210b-408
3.11	Sear	210b-409
3.12	Latch Assembly	210b-301
3.13	Latch-Half	210b-410
3.14	Safety Assembly	210b-203
3.15	Knob	210b-411
3.16	Packing Nut	210b-412
3.17	Washer	210b-413
3.18	Packing	210b-414
3.19	Adapter	210b-415
3.20	Pin	210b-416
3.21	Case	210b-417
3.22	Rear Cover Plate	210b-418
3.23	Gasket, Rear Cover Plate	210b-419
3.24	Front Cover Plate	210b-420
3.25	Gasket, Front Cover Plate	210b-421

3. Parts cont..........

	Part Name and Description	Drawing Number
3.26	Clamping Frame	210b-422
3.27	Pivot Screw	210b-425
3.28	Stop Pin	210b-426
3.29	Washer, Latch Pin	210b-431
3.30	Latch Pin	210b-432
3.31	Roller, Latch Pin	210b-433
3.32	Retainer	210b-434
3.33	Cap	210b-435
3.34	Gasket, Cap	210b-436
3.35	Pin	210b-437
3.36	Wire Lug	210b-438
3.37	Plug	210b-439
3.38	Gasket, Plug	210b-440
3.39	Stop Spring Assembly	210b-204
3.40	Stop Spring	210b-441
3.41	Holder, Stop Spring	210b-442
3.42	Rivet, Stop Spring	210b-443
3.43	Screw, Stop Spring	210b-444
3.44	Tension Spring	210b-445
3.45	Latch Stop	210b-446
3.46	Pin	210b-448

Screw No. 4-40 x 3/8" Lg. R. H. Mach. (Steel)
Screw No. 4-40 x 1/2" Lg. R. H. Mach. (Steel) (Phillips)
Screw No. 2-56 x 3/16" Lg. R. H. Mach. (Steel)
Screw No. 1-72 x 1/2" Lg. R. H. Mach. (Brass)
Drive Screw Parker-Kalon Type U No. 00 x 1/8" Lg. (Steel)
Washer, Lock, Flat, Internal Tooth No. 4 size

3. Parts cont..........

	Part Name and Description	Drawing Number
3.47	Dial 24-Hour	210a-466
3.48	Final Movement Assembly	210a-101
3.49	Winding Key Assembly	210a-214
3.50	Main Packaging Assembly	210b-501

4. **Materials** All materials used in the manufacture and packaging of the Mechanism shall be in strict accordance with those required by the detail drawings listed in Section 3 and the list of packaging materials in Section 10 of this Specification.

5. **Finish** All finishes given and finishing methods used for parts and/or assemblies of the Mechanism shall be in strict accordance with those required by the detail drawings listed in Section 3 of this Specification.

6. **Dimensions**

6.1 All dimensions of components, packing and packaging shall be in strict accordance with those required by the detail drawings listed in Section 3 and the description of packaging in Section 10 of this Specification, except as noted below:

6.1.1 In the event that the watch movement used in the Mechanism is different from that used in the original production, for which this Specification is written, the dimensions controlling the mounting and alignment of the movement and its associated accessories shall be altered to provide for their satisfactory placement within the Mechanism case.

7. Assembly

7.1 The component parts and sub-assemblies of the Mechanism shall be assembled in strict accordance with the Final Assembly, Drawing 210b-101 of this Specification. The packaging assembly shall be in strict accordance with the description of packaging in Section 10 and the Final Packaging, Drawing 210b-501, of this Specification.

7.2 In addition to the general requirements listed above, the Contractor shall take all necessary steps to insure that the following procedures are accomplished during the assembly of the Mechanism:

7.2.1 All component parts and sub-assemblies of the Mechanism shall be entirely free from chips, burrs, dirt, lint and other sources of potentially loose material prior to their assembly into the Mechanism. In keeping with this requirement, the Contractor shall keep the watch movements in their individual unit packages as long as possible before their assembly into the Mechanism.

7.2.2 The Mechanism Case, Drawing 210b-417, shall be completely degreased and all chips and burrs shall be removed from cavities and tapped holes prior to painting. The use of vapor degreasing as a sole method of cleaning is prohibited; the use of a liquid solvent and a method of agitation is required by this Specification.

7. **Assembly** cont..........

7.2.3 All gasket faces and screw threads shall be free of all grease and oil, paint, or other materials after painting and before assembly, except where a grease lubricant is required by the detail drawings listed in Section3 of this Specification.

7.2.4 The thread sealing compound used to seal threaded joints in the Mechanism assembly shall not be applied in excessive quantities. All excessive runs of sealing compound shall be wiped clean immediately after the joints have been fully taken up in the assembly process.

7.3 In addition to the precautions cited above, the Contractor shall insure that the following adjustments are made to each Mechanism at appropriate times during the assembly process. In general, the Contractor shall take all necessary steps to insure that during the assembly process the watch movements are given the maximum protection against dirt, lint, high humidity, contamination by perspiration fingerprints and damage from physical shock.

7.3.1 The Tripping Lever torsion springs shall be adjusted to deliver at least seven (7) grams force at the point at which the Tripping Lever rides on the Hour Disc. This adjustment shall be accomplished prior to the installation of the watch movements into the Mechanism Cases.

7. Assembly cont..........

7.3.2 The firing linkages shall be adjusted to insure that the Latch Assembly is entirely free from binding and will fall into place under its own weight when the Case is held vertically. This operation may be accomplished prior to the installation of the watch movements into the Mechanism Cases.

7.3.3 The positive starter actions shall be adjusted to insure that the start-and-stop action is correct and will both start and stop the watch movement balance wheel in a positive manner.

7.3.4 The watch movement Minute Hands and Hour Disc Indexes shall both be adjusted to align with the "FIRE" index mark at the time that the Tripping Lever falls through the slot in the Hour Disc and causes release of the firing linkage.

7.3.5 After the above adjustments have been made, each Mechanism shall be cocked, a delay of 23 Hr - 45 Min set, the watch movements fully wound and the Mechanisms run for at least one (1) full delay cycle to the firing point. Each watch movement shall be so regulated as to yield a maximum cumulative running error, in the face-down position, of zero (0) minutes FAST to two (2) minutes SLOW in twenty four (24) hours. In this adjustment, the use of an electronic beat-rate timer has been found helpful. In the use of such a timer, it has been found satisfactory to regulate the movement, in the face-down position, after a four (4) to six (6) hour run from a fully wound start, so that the instantaneous

7. Assembly cont..........

7.3.5 cont..........

beat rate at that time indicated a zero (0) to minus (slow) thirty (-30) second error. With this regulation it has been found that the cumulative error of a normal watch movement over a twenty-four (24) hour period is usually within the limits specified. It should be noted however, that this Specification requires that each movement be timed by the actual observation of a full twenty-four (24) hour run, and the use of the electronic beat-timer alone is not satisfactory.

8. Inspection The following Sections describe the nature and procedures for the inspections of the Mechanism.

8.1 For purposes of production and inspection control, a production lot shall be one hundred (100) assembled and adjusted Mechanisms, as taken sequentially from the production line.

8.2 Inspection of the Mechanisms shall consist of the following parts:

8.2.1 A Contractor's Inspection, performed by the Contractor, after assembly and adjustment of the Mechanisms in a production lot, but prior to their submission to the Inspector for Acceptance Inspection.

8.2.2 An Acceptance Inspection, performed by the Inspector or Inspector Agency designated by the Contracting Authority.

8. Inspection cont..........

8.2.3 A Pre-Packaging Inspection, performed by the Inspector or Inspection Agency, after preparation of the accepted Mechanisms by the Contractor for final packaging.

8.3 During the Inspection periods required by this Specification, the Contractor shall provide the following services:

8.3.1 Adequate tools, equipment, gages, and a storage and working area for use by the Inspector in the performance of the Acceptance Inspection and Pre-Packaging Inspection required by this Specification.

8.3.2 Access by the Inspector to the Contractor's inspection records and inspection area at all reasonable times during the Inspection periods required by this Specification.

8.4 The Inspection Procedures shall consist of the following:

8.4.1 The Contractor's Inspection shall include the following:

8.4.1.1 Each Mechanism shall be run through three (3) full delay cycles. Each Mechanism shall be cocked, a delay of 23 hr - 45 Min set, the watch movement fully wound, and the Mechanism started and run in the face-down position. The cumulative running error, in minutes, as referred to a standard, alternating-current electric clock, shall be observed and recorded after a running time of between twenty-three (23) and twenty-four (24) hours has elapsed. The cumulative error of any single run shall not exceed the range of zero (0) minutes FAST and two (2) minutes SLOW for any Mechanism.

8. Inspection cont..........

8.4.1.2 Each Mechanism shall be run through three (3) tripping time tests to determine the error, in minutes, of the actual firing of the firing linkage. Each mechanism shall be cocked, a short delay set, and run in the edge-up position. The tripping error, in minutes, shall be observed and recorded. This error shall not exceed plus or minus two and one half (2½) minutes from the "FIRE" index in any run for any Mechanism. During this test, the freedom of the firing linkage and the Striker shall be noted. There shall be no tendency of the firing linkage or the Striker to bind or hang-fire after the firing point has been reached. At the completion of this test, the Striker and Striker Spring shall be removed and the Striker bore shall be brushed clean of all chips and burrs dislodged during the test firings.

8.4.1.3 Each Mechanism shall be subjected to an underwater leakage test. The Mechanism cases shall be charged with thirty (30) lbs/sq. in. gage of oil-pumped nitrogen gas by means of a gasketed filler tube screwed into the Striker case hold threads. The Cases shall be submerged in at least six (6) inches of clean, oil-free water and all leaks, as evidenced by repetitive gas bubbles, shall be sealed by means of tightening the gasket retainer screws. After tightening of the gasket retainer screws, there shall be no evidence of leakage during a three (3) minute submersion period. The tightening of a joint sealed with sealing compound is prohibited; all such leaks shall be sealed by the removal, reapplication of sealer to, and the replacement of the leaking component, followed by a re-test for leakage.

8. Inspection cont..........

8.4.1.4 After completion of the tests outlined above, each Mechanism passed as acceptable shall be prepared for the Acceptance Inspection as follows:

a) Each Mechanism shall again be run for a period of at least twenty-four (24) hours in the face-down position. The firing linkage need not be cocked for this run-in period.

b) Immediately after the run-in period required above, each Mechanism shall be cocked, a delay of 23 Hr - 45 Min set, the watch movement fully wound, the movement stopped, and the Mechanisms presented as a production lot to the Inspector.

8.4.2 The Acceptance Inspection shall include the following:

8.4.2.1 Immediately upon receipt of the Mechanisms from the Contractor, the Inspector shall satisfy himself that each delay setting is correctly made for a period of 23 Hr - 45 Min. He shall then cause each mechanism to be started, making suitable time allowances in the recorded starting time of each Mechanism for the exact time of starting, and to be run in the face-down position. The cumulative error, in minutes, referred to true corrected time, shall be noted and recorded for each Mechanism after a running period of between twenty-three (23) and twenty-four (24) hours has elapsed. The cumulative error for any Mechanism shall not exceed the range of zero (0) minutes FAST and two (2) minutes SLOW.

8. Inspection cont..........

8.4.2.2 The tripping error for each Mechanism shall be noted and recorded. The tripping error shall not exceed plus or minus two and one-half (2½) minutes from the "FIRE" index for any Mechanism.

8.4.2.3 The freedom of the firing linkage and Striker shall be noted. There shall be no tendency of the firing linkage or Striker to bind or hang-fire after the firing point has been reached.

8.4.2.4 Starting with any Mechanism of his selection, the Inspector shall cause each fifth (5th) Mechanism in the production lot to be inspected to determine the proper dimensional tolerances of the Striker case hold threads. A suitable, certified "Go-No Go" screw gage shall be used for this purpose. There shall be no interference, excessive clearance or binding caused by improper screw pitch in any instance.

8.4.2.5 The same Mechanisms tested under Section 8.4.2.4 of this Specification shall be subjected by the Inspector to an underwater leakage test, as outlined in Section 8.4.1.3 of this Specification. There shall be no leakage, as indicated by repetitive gas bubbles, from any instance during an immersion of three (3) minutes.

8.4.2.6 The Inspector shall then visually inspect each Mechanism remaining as satisfactory in the production lot for the following:

8. Inspection cont..........

8.4.2.6 cont..........

a) Presence and preservation of all exterior components, including all seals and closures.

b) Absence of exterior paint blisters, peeling and chipping.

c) Absence of heavy scratches, gouges or other exterior deformations.

d) Absence of any visible chips or burrs through the window.

e) Absence of paint smudges or runs on and around the stamped, paint-filled lettering on the Mechanism back.

8.4.3 The Pre-Packaging Inspection shall consist of the following:

8.4.3.1 Immediately upon completion of the Acceptance Inspection, the Contractor shall prepare all Mechanisms in the production lot which were accepted by the Inspector, as follows:

a) The movement mainspring shall be wound to approximately one-half (½) of its full-wind travel.

b) The firing linkage shall be cocked and a delay of 1 Hr - 15 Min set.

c) The positive starter shall be run to the full "STOP" position.

d) The back plate Cap and the Shipping Plug shall be fully seated to the torque requirements in the Final Assembly, Drawing 210b-101 of this Specification.

8. Inspection cont..........

8.4.3.2 Upon completion of these preparations by the Contractor, the Inspector shall visually inspect each Mechanism remaining in the production lot to insure that the proper delay is set, the firing linkage is cocked and the watch movement is stopped.

9. Acceptance and Rejection Standards

9.1 The Contractor's Inspection shall be accepted by the Inspector upon receipt from the Contractor of an affidavit stating that each Mechanism in the production lot has been adjusted and inspected, in accordance with and meets the requirements of, Section 7 and Section 8.4.1 of this Specification.

9.2 The Acceptance Inspection

9.2.1 The Acceptance of the production lot shall be made by the Inspector if all Mechanisms in the lot meet the requirements of Section 8.4.2 of this Specification.

9.2.2 The Inspector shall be governed by the following rejection table in the event that any Mechanism is rejected under the provisions of Section 8.4.2 of this Specification:

	Failure	Failures Allowed	Reject if Failures Exceeded
9.2.2.1	Leakage in underwater test during 3 minutes immersion	0	Lot
9.2.2.2	Failure in gaging of case hold threads	0	Lot
9.2.2.3	Cumulative running error in excess of allowable range	0	Unit
9.2.2.4	Tripping error in excess of allowable range	0	Unit
9.2.2.5	Firing linkage and/or Striker bind or hang-fire	0	Unit
9.2.2.6	Chips, burrs, etc. visible through window	0	Unit
9.2.2.7	All other causes in Section 8.4.2.6	2	Lot

9. Acceptance and Rejection Standards cont.........

9.2.3 In the event that a production lot is reduced in number to less than its original one hundred (100) Mechanisms, there shall be no attempt made to replace the deficit with Mechanisms from another lot. The Production Lot shall be prepared for packaging with whatever number of Mechanisms have been accepted by the Acceptance Inspection.

9.3 The Pre-Packaging Inspection

9.3.1 Acceptance of the Mechanisms in the pre-packaging inspection shall be made by the Contractor when all Mechanisms have met the requirements of Section 8.4.3 of this Specification. No rejection of the lot or of individual mechanisms shall be made; the Contractor shall make corrections, as directed by the Inspector, at the time of the Pre-Packaging Inspection.

10. Packing and Packaging

10.1	Unit Package Components	Drawing or Specification Number
10.1.1	Clockwork Mechanism, assembly	Spec 210b Dwg 210b-101
10.1.2	Adapter, special, unit package	Spec 210c-101 Dwg 210c-101
10.1.3	Cocking device	Spec 210c-2 Dwg 210c-102
10.1.4	Detonator, M-34	Spec 50-0-1C/A3
10.1.5	Primer, std. coupling base, with plastic cap	Spec JAN-B-268 or Fed QQ-2-363, or U.S.Army 57-93-2
10.1.6	Wire, Coil	Dwg. 210b-501
10.1.7	Can, tear strip, metal	Dwg. 210b-501

10. Packing and Packaging cont..........

10.1.8	Tube, collapsible, containing obscuring compound	Spec 210c-3
10.1.9	Tube, mailing, for Detonator M-34	Spec PPP-T-495
10.1.10	Tube, mailing, for cocking device	Spec PPP-T-495
10.1.11	Disc, cushioning	Dwg. 210b-501
10.1.12	Liner, cushioning	Dwg. 210b-501 Spec MIL-C-11791
10.1.13	Material, cushioning	Spec UU-C-843
10.1.14	Tape, adhesive	Spec JAN-P-127

10.2 Description of Unit Package Components

10.2.1 The Clockwork Assembly shall be as shown in the Final Assembly, Drawing 210b-101, of this Specification.

10.2.2 The Adapter, Special, shall be as shown in the assembly, Drawing 210c-101, and shall be unit-packaged as required by Specification 210c-1.

10.2.3 The Cocking Device shall be as shown in the Assembly, Drawing 210c-102.

10.2.4 The Detonator, M-34, shall be provided by the Contracting Authority, in accordance with Spec 50-0-1C/A3, U S Army Drawing 73-2-330.

10.2.5 The Primer, standard coupling base, with plastic cap, shall be as supplied by the Contracting Authority and in accordance with Specification JAN-B-268, QQ-2-363 or U S Army 57-93-2.

10. Packing and Packaging cont..........

10.2.6 The wire, coil, shall be made up of fully annealed, soft iron wire, single strand, of approximately 0.025" diameter x 10' long, having either a patented, blued or black oxide and oiled finish. The strand shall be wound into a coil of approximately 1-3/4" I. D. and both ends shall be crimped to prevent unwinding.

10.2.7 The can, metal, tear-strip shall be in general accordance with Specification MIL-C-1243, Type 3, and in strict accordance with Drawing 210b-501.

10.2.8 The tube, collapsible, with obscuring compound, shall be in accordance with Specification T210c-3.

10.2.9 The tube, mailing, for detonator M-34, shall be of paper, spiral wound, size 5/8", I.D. x 2 1/4" long, in accordance with Specification PPP-T-495.

10.2.10 The tube, mailing, for both cocking device and coupling-base primer, shall be of paper, spiral wound, size 5/8" I. D. x 2 1/4" long, in accordance with Specification PPP-T-495.

10.2.11 The disc, cushioning, shall be made of double faced corrugated fiberboard, type W_5C or W_6C, size 3 31/32" D x 1/8" thick.

10.2.12 The liner, cushioning, shall be of single-face corrugated fiberboard, size 2 1/4" x 25", the corrugations parallel to the 2 1/4" dimension, in accordance with Spec MIL-C-11791, type 3B.

10. Packing and Packaging cont..........

10.2.13 The cushioning material shall be cellulosic, non-hygroscopic medium density, in accordance with Specification UU-C-843, Type III, Class B, and may be supplied in roll or flat form.

10.2.14 The tape, adhesive, pressure sensitive, shall be of sizes 1/2" and 1/4" width, and in accordance with Specification JAN-P-127.

10.3 Method of Sub-Packaging

10.3.1 The Detonator Sub-Package shall be as follows:

10.3.1.1 One (1) Detonator, M-34, shall be inserted into one (1) mailing tube, detonator (10.2.9) and centered therein.

10.3.1.2 Each end of the Detonator shall be cushioned with cushioning material (10.2.13) sufficiently tamped to hold it firmly in place within the tube.

10.3.1.3 Each end of the tube shall then be taped to hold the contents firmly in place. Two (2) strips of tape, size 1/4" x 2", shall be placed at right angles over each end and pressed firmly onto the tube.

10.3.2 The Special Adapter Sub-Package shall be in accordance with Specification 210c-1.

10.3.3 The Cocking Device Sub-Package shall be as follows:

10.3.3.1 One (1) Cocking Device (10.2.3) shall be placed into one (1) mailing tube (10.2.10), cap end out, and pressed firmly into place so that the cocking device cap is flush with the end of the tube.

10. Packing and Packaging cont..........

10.3.3.2 Two (2) strips of tape, size 1/4" x 2", shall be placed at right angles over the end and pressed firmly onto the tube.

10.3.3.3 Cushioning material shall then be tamped firmly into the open end of the tube in sufficient amount to completely cover and cushion the cocking device spindle within the tube.

10.3.3.4 One (1) Primer, standard coupling base, shall then be inserted into the tube, primer end out, and pushed firmly into place so that the primer end is approximately 1/8" or more within the tube.

10.3.3.5 Cushioning material shall then be tamped firmly into the open tube end in sufficient amount to completely cover and cushion the Primer to a depth of at least 1/8".

10.3.3.6 The open end shall then be taped as in Section 10.3.3.2.

10.4 Clockwork Mechanism Preparations

10.4.1 With the Clockwork Mechanism prepared as per Section 8.4.3 of this Specification, it shall then be evacuated and gas-filled as follows:

10.4.1.1 The back plate cap shall be loosened until it is held in place by a single thread.

10. Packing and Packaging cont..........

10.4.1.2 The Mechanism shall then be placed, face-up, in a bell-jar or other evacuation chamber, and the chamber evacuated to a vacuum of at least twenty-four (24) inches of mercury. When this pressure has been reached, the Mechanism shall be allowed to remain for at least one (1) minute before gas purging is begun.

10.4.1.3 After remaining at the prescribed pressure for one (1) minute, the vacuum pumping line shall be closed and oil-pumped nitrogen gas, commercial grade, shall be allowed to fill the chamber. A regulated rate of nitrogen pressure within the chamber shall be established so that it shall require approximately two (2) minutes to reach atmospheric pressure.

10.4.1.4 The Mechanism case shall then be removed from the bell-jar and closed and sealed with the back plate cap.

10.5 Unit Package Assembly

10.5.1 The individual unit package corrugated wrappers and cushioning shall be dried by heating for at least thirty (30) minutes at 220°F in a well-vented oven.

10.5.2 The sub- and unit-package components shall then be assembled in the unit-package can in accordance with Drawing 210B-501 of this Specification. The dried corrugated wrappers and cushioning shall be exposed to ambient conditions for as little time as possible during this operation.

10. Packing and Packaging cont..........

10.5.3 The unit package can shall then be double-seam sealed as soon after assembly as possible, in order that moisture re-absorption may be held to a minimum.

10.6 Gross Packaging

10.6.1 No gross package has been prescribed for this Device.

APPENDIX C

PERSONNEL ASSOCIATED WITH THE PROJECT

Appendix C - Personnel Associated with the Project.

Arthur D. Little Inc.

Anderson, H. M.	Project Engineer
Knight, H. F., Jr.	Project Engineer
Kreidl, Dr. E. L.	Group Leader
Lothrop, Dr. W. C.	Division Head
Stowe, J. P.	Project Leader

Leeds & Northrup Company

Wilson, Dr. B. J.	Consultant
Murray, G. E. R.	Consultant
Peters, J. C.	Consultant
Perley, G. A.	Consultant

New Haven Clock & Watch Company

Denegre, Louis	Chief Engineer
Field, J. E., Jr.	Contracting Officer
Marches, Charles	Asst. Chief Engineer

Thomaston Special Tool Company

DeBisschop, Frank	Co-owner
Richtmyer, W. C.	Co-owner

Canadian Radium & Uranium Corp.

Gorlin, Boris	Chief Engineer

APPENDIX D

ADL INTERIM REPORT NO. 1 - "INVESTIGATION OF LUBRICANT PERFORMANCE AT LOW TEMPERATURES IN THE 24-HOUR CLOCKWORK DELAY MECHANISM"

August 10, 1954

INTERIM REPORT NO. I

INVESTIGATION OF LUBRICANT PERFORMANCE AT LOW TEMPERATURES IN THE 24-HOUR CLOCKWORK DELAY MECHANISM

C-58214-AB

QK-15-529-AB

ARTHUR D. LITTLE, INC.

August 10, 1954

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INTRODUCTION

The decision of whether or not to lubricate a watch movement and, if lubricated, the choice of the lubricant to be used, are factors which can materially effect both the storage life and operating limitations of the entire mechanism assembly. In view of the fact that so much depends on the selection made, it was decided early in the program to investigate and weigh both the advantages and disadvantages of bare and lubricated movements in order to determine which course should be taken for the 24-Hour Clockwork Delay Mechanism.

While the use of unlubricated watch movements has been successful under limited conditions to attain good low temperature performance, the fact remains that very little is known about the storage life of such movements. None of the Armed Forces recommends that an unlubricated movement be stored except for very short periods; the same limitation is observed by commercial watch manufacturers. This recommendation is apparently the result of the fear that unlubricated pivots and bearings cannot withstand the tendency to "freeze" when left standing under relatively heavy bearing loads for long periods of time. Although the initial timing tests conducted on the so-called "dollar" movement showed that the unlubricated movements were capable of performance equal or superior to that of lubricated movements, the mutual arbitrary decision was made to eliminate further consideration of the former for reasons of storage life.

Based on the results of this initial test program and the recommendations of both the Armed Forces and Armour Research Institute, all but two (2) liquid and one (1) solid lubricant were eliminated. An attempt was made to evaluate a molybdenum disulfide-in-solvent lubricant; this, however, was not successful in this case for lack of a satisfactory method of introducing the material into the movement in small, uniform quantities required for this application.

The remaining lubricants, Frankford Arsenal #434 fuse oil and Consolidated Vacuum Corporation "Convalube A" were subjected to both a comparison of published characteristics data and a series of low-temperature operational tests in the 24-Hour Clockwork Delay Mechanism. There was little difference to be found between these oils as regards their published specifications and characteristics data except in the case of their temperature-viscosity curves; Frankford Arsenal oil showed a considerably lower viscosity index.

Since the only apparent difference between the characteristics of these oils was that of viscosity, it was mutually decided between the Client and Arthur D. Little, Inc., that a satisfactory comparison could be made on the basis of low-temperature performance in the 24-Hour Clockwork Delay movement, and that the selection of the oil to be used in the production of these movements could be based on the results of this test.

CONCLUSIONS

As the result of experience gained during the preparation of movements for the low-temperature test program and the data gathered from that same program, the following conclusions have been drawn.

1) "Convalube A" oil and Frankford Arsenal #434 fuse oil are both satisfactory lubricants for the 24-Hour Clockwork Delay movement at room temperature, although the FA #434 oil is somewhat more difficult to properly introduce into the movement and requires more careful timing of the movement after lubrication.

2) "Convalube A" oil yields satisfactory results in this particular application at temperatures down to -45 C (-49 F).

3) FA #434 oil will not yield satisfactory results in this particular application at -45 C or below.

4) For reasons unknown at present, continuous low-temperature operation of the mechanisms, with the naturally increasing amounts of condensed moisture within the case, tends to cause more failures of movements lubricated with FA #434 than with "Convalube A" oil.

5) There is a definite indication of cumulative tendency toward failure of all movements which, regardless of the lubricant used, are subjected to continuous low-temperature operating conditions.

RECOMMENDATIONS

Based on the conclusions drawn in the above paragraph, the adoption of the following actions is recommended:

1) That "Convalube A" be selected as the primary lubricant for the 24-Hour Clockwork Delay Mechanism movement.

2) That when the movements are lubricated as in (1) above, the minimum operating limit be set at -45 F.

3) That the Mechanism cases be carefully purged of air and an atmosphere of dry, oil-pumped nitrogen gas be introduced and sealed into the case immediately prior to packaging, to reduce both the amount of free moisture available to form frost at low temperatures and the amount of free oxygen available to cause oil deterioration during storage.

DESCRIPTION OF TESTS

The low-temperature test battery was divided into two (2) parts, herein called the First and Second Battery respectively. These test batteries were run at different times, under the conditions outlined below:

1) First Test Battery

a) Group A: Seven (7) mechanisms, selected at random from a group of 80, were thoroughly cleaned and rinsed in the L & R instrument washing machine, and then were relubricated with "Convalube A," Lot No. 111, a sample from Consolidated Vacuum Corporation. These mechanisms were then run for approximately 24 hours, rewound fully and, after an additional five (5) hours' running time, timed to an instantaneous zero beat rate error with the Watchmaster timing instrument.

b) Group B: Seven (7) mechanisms, previously selected at random from the original lot of 89 delivered for test and relubricated with FA #434 oil at that time, were run for approximately 24 hours and then retimed as described above for Group A.

NOTE: The lubrication of bothg roup A and B was done by the same operator.

2) Second Test Battery

a) Group C: Ten (10) mechanisms were selected from those remaining of the original 89, and were then both run and rechecked for beat rate as described above for Group A.

This procedure allowed the original lubricant, "Convalube A," to remain in the movement reflecting the quality of factory lubrication to be expected in future mechanisms.

b) Group D: Ten (10) mechanisms were selected from those remaining of the original 89; this selection was made on the basis of excellent original performance, as indicated by the records of these movements when tested in the as-delivered condition and at room temperature. A minimum spread of timing errors at the end of each 24-hour run was considered as the criterion for excellent performance. These mechanisms so selected were then completely washed and rinsed and relubricated with FA #434 oil by the same operator who performed the relubrication of Groups A and B. As with other groups, these movements were then run and rechecked for a zero beat rate error.

All mechanisms in the First Test Battery were run at low temperatures, as indicated in the tables of data and results, Appendix B, without being brought to room temperature at any time and without nitrogen purging of the cases. The rewinding and resetting was done between runs at the temperature for the next run, but only after the mechanisms had been stabilized at that temperature for 6 hours.

All mechanisms in the Second Test Battery were run at low temperatures as above, but with the following exceptions:

1) All mechanism cases were purged with oil-pumped nitrogen before each run.

2) Between runs III and IV, the mechanisms were allowed to come to room temperature (approximately 70 F) from approximately -56 F over a period of 12 hours; this was the result of a refrigerator cabinet failure.

3) Run IV was started at room temperature and the mechanisms were then plunged into the next test temperature.

In all cases the mechanisms were placed in a vertical position, as this is the position in which the mechanisms perform poorest. All mechanisms were kept within an 18" square on a wooden platen, approximately 1" off the refrigerator cabinet floor. A liquid-in-glass thermometer was kept in the approximate center of the group for temperature indication. No air circulation was employed during the runs and the cabinet was opened only to start the mechanisms for each run and again to read dials once during the run at approximately the 23rd hour of operation. In all cases the mechanisms were marked only by number and were mixed.

RESULTS OF LOW-TEMPERATURE TESTS

The results of both the First and Second Test Batteries are tabulated below and in Appendix A as a comparison between the two lubricant groups for original room temperature performance, various low-temperature performances and finally, for a single recovery run at room temperature some 12 hours after completion of the last low-temperature run. By tabulation in this manner, the groups can be compared before, during, and after being subjected to low-temperature operation; the standard deviations computed for each group are taken as an indication of the performance of the movement-and-lubricant combinations and, as such, is a valid basis for comparison.

This concept of comparison of standard deviations, however, must be tempered somewhat by the fact that, in the First Test Battery, moisture accumulation probably had an adverse effect on all movement operation, although to what degree is not known. In the case of the Second Test Battery, however, this limitation no longer is effective, since all mechanisms were purged with nitrogen at each run.

TABLE I - SUMMARY OF RESULTS FOR FIRST TEST BATTERY

	Better Group		Worse Group		
	Group	Std. Dev.	Group	Std. Dev.	Notes
1) Original performance	A	2.45 min.	B	6.94 min.	7 samples each
2) Run II, -52 to -56 C	A	8.28	B	25.9	4 samples each
3) Run III, -45 C	B	1.40	A	11.4	7 samples A 2 samples B**
4) Run IV, -48 C	A	5.82	B	7.07	5 samples A 2 samples B**
5) Run V, room temperature	A	6.45	B	9.10	5 samples A 3 samples B**

NOTE: Group A lubricated with "Convalube A" oil.
Group B lubricated with FA #434 oil.

TABLE II - SUMMARY OF RESULTS FOR SECOND TEST BATTERY

	Better Group		Worse Group		
	Group	Std. Dev.	Group	Std. Dev.	Notes
1) Original performance	D	1.82 min.	C	3.11 min.	10 samples each
2) Run IV, -52 C	C	9.90	D	24.8	7 samples C 3 samples D**
3) Run V, -46 C	C	5.20	D	10.3	7 samples C 3 samples D**
4) Run VI, room temperature	D	4.89	C	12.9	9 samples C 7 samples D
5) Run VI, using selected data*	C	3.02	D	4.89	See note below

NOTE: * denotes calculation in which a -43 minute error recorded for Serial No. 26 mechanism was eliminated to illustrate the extremely heavy weighting effect on the Group C calculations of this single piece of data. See "Discussion of Results" section.

** It is recognized that a calculation of standard deviation based on only three (3) data points is questionable; however, in view of the fact that only three (3) of the 10 movement FA #434 samples ran and produced usable data, the calculation is justified.

Group C lubricated with "Convalube A" oil.
Group D lubricated with FA #434 oil.

DISCUSSION OF RESULTS

1) First Test Battery

Although the First Test Battery did not yield as well as the Second to statistical analysis as employed, it is apparent from the -45 C results that "Convalube A" oil performance is equal to that of FA #434. When another variable, that of the number of movements which failed to run at that temperature, is considered, the "ConvalubeA" oil appears to be superior for this particular application. The statistical treatment of the original movement performance, however, indicates that the "Convalube A" group (Group A) was superior in operation to the FA #434 group (Group B), and on that basis the resulting difference in low-temperature performance as well as recovery could perhaps be questioned. It can be definitely stated, without fear of question, that in the First Test Battery the movements lubricated with "Convalube A" did not show the extreme tendency toward failure in test that was apparent with those lubricated with FA #434 oil.

2) Second Test Battery

In this test battery the movements for the FA #434 oil were selected on the basis of excellent original performance to insure that the movements would be mechanically of high quality and that the statistical treatment of their performance would indicate that they were at least equal to the "Convalube A" group. The analysis shows that, in contrast with the First Battery, the Second Battery FA #434 movements (Group D) were significantly better than their competitors, Group C at room temperature. No difference in handling was allowed between the two groups from the time each movement was lubricated, and no known external factor was introduced to invalidate the results.

Statistical treatment of the performance of both groups in the Second Test Battery has been summarized in Table II. The low-temperature performance of the "Convalube A" lubricated movements was superior in the two test runs selected for analysis. At the final, room temperature recovery run the FA #434 oil group reasserted its superiority, as was to be expected since it was the originally better group of mechanisms. This was also the case in the First Battery, in which the originally better group showed a better recovery from the low-temperature operational tests. However, in the Second Battery, the difference in recovery at room temperature was highly influenced by the relatively poor performance of a single movement in the "Convalube A" group (Group C). The recovery of this entire group (Group C) becomes superior, thus reversing the previous tendency, if this one movement is dropped from the calculation of significant differences. A similar treatment of the Group D data, by removal of the worst movement performance in recovery, does not change the results in a like manner, and, in a comparison of "cropped" data for the two groups, the "Convalube A" group remains superior not only in low-temperature performance but also in recovery after low-temperature operation. It is believed that this fact should be given considerable weight in the final evaluation of performance of the two lubricants.

In general, it may be said that the performance of movements lubricated with "Convalube A," in all cases down to -45 C, was at least equal to that of movements with FA #434. When the higher rate of failure of movements lubricated with FA #434 oil is considered, it is apparent that the "Convalube A" oil is superior to FA #434 for use in the 24-Hour Clockwork Delay Mechanism movement.

APPENDIX

A

ANALYSIS OF ORIGINAL SAMPLES, FIRST TEST BATTERY

Group A - Convalube A		Group B - FA #434	
Sample	Vertical Errors	Sample	Vertical Errors
41	-1, +2	30	
51		32	-5, -3
59	-2, 0	38	-10, 0
63	-3, 0	48	
72	0, +1	58	+10, +6
82	+1, +1	80	+8, +7
83	-5, -5	93	-5, -5

$\Sigma\epsilon_A = -11$ $\qquad$ $\Sigma\epsilon_A = +3$

$\Sigma\epsilon_A^2 = 71$ $\qquad$ $\Sigma\epsilon_A^2 = 433$

$n_A = 11$ $\qquad$ $n_A = 10$

$$\sigma^2 = \text{variance} = \frac{n\quad{}^2 - (\quad)^2}{n(n-1)}$$

$$\sigma_A^2 = 6.00$$

$$\sigma_B^2 = 48.00$$

$$F = \text{entry factor for probability tables} = \frac{\sigma\ B}{\sigma\ A} = \frac{48.0}{6.0} = 8.0$$

m = 10)
n = 9) degrees of freedom

Probability that groups are different is 99.5%, Group A being the better of the two.

$\sqrt{\sigma^2}$ = standard deviations, minutes

$\sqrt{\sigma_A^2} = \sqrt{6.00} = 2.45$ minutes

$\sqrt{\sigma_B^2} = \sqrt{48.00} = 6.94$ minutes

<u>Indication of Original Group Differences:</u>

% Errors	68%	95%	99.7%
Group A	2.45 min.	4.9 min.	7.35 min.
Group B	6.94	13.9	20.8

ANALYSIS OF ORIGINAL SAMPLES, SECOND TEST BATTERY

Group C - Convalube A		Group D - FA #434	
Sample	Vertical Errors	Sample	Vertical Errors
02	-3, -2	03	+2, +1
26	-1, -1	34	-2, -2
47	+6, +6	40	-1, 0
66	-2, 0	55	-3, -1
70	0, -1	64	-2, -1
75	-6, -2	67	-1, 0
78	0, 0	73	+4, +1
84	+1, +1	85	+2, +1
86	-5, -2	94	+2, 0
92	-6, -1	95	-2, -2

$\Sigma_C = -18$ $\qquad$ $\Sigma_D = -4$

$\Sigma^2_C = 200$ $\qquad$ $\Sigma^2_D = 64$

$n_C = 20$ $\qquad$ $n_D = 20$

$^2_C = 9.67$

$^2_D = 3.32$

$$F = \frac{9.67}{3.32} = 2.90 \qquad m = 19 \qquad n = 19$$

Probability that groups are different is between 99 and 97.5%, Group D being the better of the two.

$\sigma_C = \sqrt{9.67} = 3.11$ minutes

$\sigma_D = \sqrt{3.32} = 1.82$ minutes

Indication of Original Group Differences, Groups C & D

% Errors	68%	95%	99.7%
Group C	3.11 min.	6.22 min.	9.33 min.
Group D	1.82	3.64	5.46

Reference: INTRODUCTION TO SCIENTIFIC RESEARCH, Wilson, McGraw-Hill, 1953. Page 206, 'Variance Ratio Test' (Schnedeker 'F' Test).

APPENDIX

B

FIRST TEST BATTERY RESULTS

		LOW TEMPERATURE RUNS					
		I	II	III	IV	V	
		Hi -53 C Lo -61 C	Hi -52 C Lo -56 C	-45 C	-48 C	Room Temp	
No.	Lube Type	Running Error, Minutes in 23^H-45^M					Notes
41	Conv.	x	x	-5	-16	-2	
51	"	-9	x	-3	-4	+7	
59	"	x	-4	-7	-19	out	Broken Spring
63	"	-15	+10	-11	-11	x	
72	"	-39	+7	-11	-11	+5	
82	"	x	-7	-18	x	+3	
83	"	x	x	-33	x	-7	
30	FA 434	x	x	x	x	out	Broken Spring
32	" "	x	+14	0	-12	-2	
38	" "	x	0	+2	-2	+5	
48	" "	+9	-40	x	x	+16	
58	" "	x	-41	x	x	x	
80	" "	x	-16	x	x	out	Broken Spring
93	" "	x	x	x	x	out	Broken Spring

SECOND TEST BATTERY RESULTS

No.	Lube Type	LOW TEMPERATURE RUNS — Running Error, Minutes in 23^H-45^M: I (-61C)	II (-61 C)	III (-56 C)	IV (-52 C)	V (-46 C)	VI (Room Temp)	Notes
02	Conv.	x	x	x	out	-	-	Broken Spring
26	"	x	x	x	-7	x	-43	
47	"	x	x	x	0	-4	-1	
66	"	-49	x	x	-25	-15	-6	
70	"	-11	-50	x	-12	-7	-4	
75	"	x	x	x	x	x	-7	
78	"	-21	-30	x	-15	-9	-5	
84	"	-20	x	x	-25	-7	-2	
86	"	-24	x	x	-27	-19	-10	
92	"	-21	x	x	-23	-9	-8	
03	FA 434	x	x	x	-9	-32	-14	
34	"	x	x	x	x	x	-15	
40	"	-8	x	x	out	-	-	Broken Spring
55	"	x	x	x	x	x	-13	
64	"	x	x	x	out	-	-	Broken Spring
67	"	x	-23	x	-39	x	-8	
76	"	x	x	x	0	x	-2	
85	"	-21	x	x	x	-12	-8	
94	"	x	x	-16	-16	-26	-15	
95	"	x	x	x	x	x	out	Broken Spring

All movement cases purged with nitrogen gas prior to start of each run.

APPENDIX E

ADL INTERIM REPORT NO. 2

INVESTIGATION OF GASKET AND SEALING MATERIALS

FOR THE 24-HOUR CLOCKWORK DELAY MECHANISM

September 15, 1954

INTERIM REPORT NO. 2

INVESTIGATION OF GASKET AND SEALING MATERIALS FOR THE 24-HOUR CLOCKWORK DELAY MECHANISM

C-58214-AB

QK-15-529-AB

ARTHUR D. LITTLE, INC.

September 15, 1954

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INTRODUCTION

During the initial phases of testing the 24-Hour Clockwork Delay Mechanism, it became apparent that the original gasket materials, configurations and methods of sealing used to complete closure of the case and its operating parts were possible sources of both operational difficulty and total mechanism failure. With these difficulties recognized and their sources determined, it was felt that an investigation should be made into the properties of various sealing compounds and rubber-like gasket materials to determine whether or not more positive closures might be specified for this particular application and set of operating requirements. The investigation was limited, however, by the fact that no freedom of design was allowed in the majority of closures for the Mechanism; the conclusions and recommendations presented in the following sections reflect this limitation.

CONCLUSIONS

1) That the original gasket materials, Armstrong Cork Company "Corprene" grades DC-100 and DC-118, mixtures of cork and neoprene, exhibit a high initial creep under compression, making them unsuitable for use as static seals for this particular application.

2) That the "Corprene" DC-100 material exhibits a severe tendency to stick tightly to metal when, in service as a moving seal on the rear plate cap, it has become water-wet, frozen of has been stored in a compressed condition for relatively long periods of time.

3) That the "Corprene" DC-118 material, when cut into small sizes for spindle gland packing rings, exhibits a tendency to break up under use, allowing small particles to enter the Mechanism case.

4) That the "Corprene" materials do not resist swelling, softening and other declines in physical properties as well as other commercially available materials when exposed to various fuels and solvents.

5) That the originally specified gasket thickness of 1/16" is excessive, allowing extrusion of gasket material and causing nonuniform gasket sealing pressures, when used in static seal applications.

6) That the adapter nuts for both the safety and positive starter spindles require a thread sealing compound to guarantee positive closure between these threads and the case.

7) That both the safety and positive starter spindles require a lubricant in their respective packing glands to act as both a sealer and anti-seize agent.

8) That the mechanism case, properly gasketed and sealed, will withstand 50 psig external water pressure and an external pressure equivalent to 40,000 feet altitude, both at room temperatures, without leakage or gasket rupture.

9) That water-vapor transmission through the gaskets and plexi-glass window is not serious over a 24-hour period, provided the case is properly gasketed and sealed.

RECOMMENDATIONS

1) That the "Corprene" DC-100 and DC-118 materials be replaced with a Buna-N synthetic rubber material meeting the requirements of Specification MIL-R-003065A (ORD), "Rubber and Synthetic Rubber Compounds; Mechanical and General Purpose," Type S, Class SB, Grade No. SB-625-B.

2) That the thickness of all flat rubber gaskets be reduced from 1/16" to 1/32".

3) That the rear cover plate cap be redesigned to allow use of a commercially available O-ring closure, and that this O-ring be made of a Buna-N compound having both low fuel and solvent swelling and low compression set characteristics similar to that specified for the flat gasket material.

4) That both the safety and positive starter spindle glands be lubricated with a silicone grease, similar to Dow-Corning Corporation DC-11, during assembly.

5) That both the safety and positive starter adapter nuts be seated in a permanent, hardening grade thread sealing compound, similar to Permatex Co., Inc., "Permatex No. 1," during assembly.

6) That both the front and rear cover plate retaining screws be seated in a permanent, hardening grade thread sealing compound, similar to "Permatex No. 1," during assembly.

7) That both the front and rear cover plate retaining screw forms be changed from a slotted-head to a recessed, Philips-head type, to allow faster and better controlled assembly under a predetermined torque setting by an air-drive, slip-clutch type screwdriver.

8) That on the present pilot production Mechanisms, the screws retaining the two (2) wire lugs on the front cover plate be seated on star-type, anti-slip washers, to prevent loosening of these screws and relaxation of gasket compression as the result of lug rotation during field usage.

9) That for future production the wire lugs be redesigned to incorporate "ears" bent down to engage the inner face of the front cover plate, preventing rotation of the lugs and the attendant loosening of retaining screws.

10) That any future design for a clockwork delay mechanism be based on a circular cross-section to take maximum advantage of simple, positive and relatively inexpensive O-ring closures.

GENERAL CONSIDERATIONS FOR CLOSURE DESIGN

The process by which a satisfactory closure is obtained is one of both design and compromise. The physical design of the components to be closed should, in general, allow for as simple, positive and inexpensive seal as is consistent with both storage and operating requirements imposed on the assembly. In this particular investigation, however, design freedom in this direction was essentially denied, and, as a result, the majority of work was done only toward the selection of materials to meet the above requirements.

The selection of a gasket or seal material is more limited than that of design under normal circumstances. With increasingly critical storage and operating requirements, it becomes apparent that there is no single, commercially available material which will provide the superior performance desired over the entire range of conditions. It is quite necessary, therefore, that a realistic evaluation be made of the storage, transport and operating conditions which the assembly and its closures must withstand. It is then possible to determine which gasket and seal material properties must be preserved and those which progressively can be compromised or even sacrificed. The final design and materials selection will then reflect an engineering compromise for the particular closure in question. If the process has been based on sound engineering judgment and reliable data, the closure will operate satisfactorily in both test and actual usage.

EVALUATION OF MECHANISM LIFETIME ENVIRONMENT

1) General Outline

There will be essentially three (3) phases which the great majority of 24-Hour Clockwork Delay Mechanisms must survive after manufacture and packaging, namely:

a) Long term storage in a nitrogen filled and sealed metal can for some unknown period of time, presumably in the order of fifteen years.

b) Transit to and temporary storage at the operating site, probably still in the unit-package can, for relatively short periods of time.

c) Actual field operation in the bare condition under various combinations of environment for a maximum of approximately 24 hours.

2) Variables to be Encountered

Within the three phases outlined above, there will be many combinations of environment variables, each variable having a direct bearing on the performance requirements of gasket and sealing materials. The individual variables expected to operate during these phases are as follows:

a) Time
b) Temperature
c) Pressure
d) Relative Humidity
e) Chemical and Solvent Action
f) Physical Stresses

3) Evaluation of Lifetime Phases

a) Long Term Storage Phase:

This phase will very probably constitute the longest single period in the lifetime of the majority of the 24-Hour Clockwork Delay Mechanisms. If the design and assembly of the unit package reduces the Mechanism environment during this period to that of an essentially pure nitrogen atmosphere, then the only variables remaining to act upon the gaskets and seals to cause deterioration are time and temperature; all other variables and influences are eliminated by the unit package. The two remaining active variables, however, must be considered to act over a very long period, probably in the order of fifteen years; it follows, therefore, that the gasketing and sealing materials chosen must be capable of withstanding this period successfully.

During this long term storage period all gaskets in the Mechanism act as static seals since neither parts nor components will be moved or activated while the Mechanism is in the unit package. As such, they must resist for a long period only the temperature conditions listed in Table I. In resisting the combined time-temperature variables in storage, these materials must:

(1) Resist attack by the silicone grease used as a gland lubricant and sealer.

(2) Resist excessive permanent set under the original closure compression.

(3) Resist softening, gumming and loss of plasticizer under high storage temperatures.

(4) Resist cracking at low storage temperatures.

b) Temporary Storage and Transit Phase:

It is to be assumed that transit and temporary storage will be accomplished with the Mechanism still in the unit package for adequate physical and environmental protection. In this condition, the same variables as were active during the long term storage will continue to act, but since this phase is of short duration, time is of relatively little importance. This leaves temperature as the single important variable to be considered.

As reported in Reference (1) and Table II, the temperature extremes encountered during temporary storage and transit are wider than those normally experienced in long term storage, and the resistance of the gasketing and sealing materials must be sufficient to withstand these conditions. To accomplish this, the materials must:

(1) Resist softening, gumming and loss of plasticizer at very high storage and transit temperatures.

(2) Resist cracking at very low storage and transit temperatures.

c) Field Usage Phase:

This phase is limited, at least in theory, by the following conditions:

(1) Operation will occur with the Mechanism removed from the unit-package can.

(2) Operation will occur at or above the lower operating temperature limit of -45°F.

(3) Operating phase will be in the order of 24 hours plus a small amount of time required to bring the Mechanism onto the intended operation site.

With these limitations in mind, the following conditions can be outlined for the operating phase; again, the gasketing and sealing materials must successfully resist not only those conditions outlined for the first two phases, but also:

(1) Resist tendency to harden and crack under flexure at lower operating temperatures when acting as a moving seal.

(2) Exhibit reasonably quick recovery from compression at all temperatures.

(3) Resist sticking to metals at all temperatures and conditions of moisture.

(4) Resist moderate cutting and abrasive action at all temperatures when used as a moving seal.

(5) Resist for approximately 24 hours the action of water, fuels, solvents and other liquids, under pressures up to 20 feet H_2O, sufficiently well to maintain a leakproof closure.

d) Summary of Material Requirements:

A summary of the qualitative material requirements dictated by each phase of the Mechanism lifetime is shown in Table I.

TABLE I

Storage, Transit and Usage Requirements for Gasket and Sealing Material Properties

Variables and Effects	Storage	Temp. Stor. & Transit: Pkg.	Temp. Stor. & Transit: Bare	Usage
Time				
1) Good resistance to heat aging	x			
2) Good resistance to "shelf aging"	x			
3) Good resistance to permanent set	x			
4) Good resistance to loss of plasticiser and lubricant	x			
5) Good resistance to exposure to silicone greases	x			
Temperature				
1) Good resistance to very high temperature softening and gumming	x	x	x	x
2) Good resistance to very low temperature cracking	x	x	x	x
3) Good resistance to very low temperature hardening				x
4) Good low temperature compression recovery				x
Relative Humidity				
1) Good resistance to water vapor transmission			x	x
2) Good resistance to dimensional change			x	x
Gas Pressure				
1) Good resistance to gas permeability			x	x
2) Good resistance to deformation under pressure			x	x

TABLE I (Continued)

Variables and Effects	Storage	Temp. Stor. & Transit: Pkg.	Temp. Stor. & Transit: Bare	Usage
Liquid Pressure				
1) Good resistance to vapor transmission			x	x
2) Good resistance to liquid absorption				x
3) Good resistance to deformation under pressure			x	x
Chemical and Solvent Action				
1) Good resistance to softening and loss of tensile strength				x
2) Good resistance to dimensional change				x
Physical Movement				
1) Good resistance to tearing				x
2) Good resistance to low temperature brittleness				x
3) Good resistance to high temperature sticking				x

CLIMATIC ENVIRONMENTS TO BE ENCOUNTERED

A summary of the maximum observed, probable and test recommendation temperatures and humidities is presented in Table II. These values shown were taken from Reference (1), Report No. 146, CLIMATIC EXTREMES FOR MILITARY EQUIPMENT, Environmental Protection Branch, R & D Division, Office of the Quartermaster General, U.S. Army, November 1951, and Reference (2), MIL-STD-210, CLIMATIC EXTREMES FOR MILITARY EQUIPMENT, 1 June 1953.

INVESTIGATION OF GENERAL MATERIALS CHARACTERISTICS

With storage and operational criteria evaluated, probable climatic extremes determined, it became necessary to obtain a relative rating of various commercially available gasketing materials for comparison of their nominal properties. These ratings were obtained from manufacturers' brochures and other published sources of information regarding rubber-like gasketing materials. With this rating the field of selection was narrowed to four materials, Buna-N, Neoprene, Thiokol and Silicone materials. The published nominal characteristics were again examined and those most applicable to the requirements of this particular problems were selected for comparison; these comparative properties are shown in Table III. It is to be noted that those properties specifically required for good long term storage life are at least of equal importance as those for proper operation; this premise is held to be valid on the basis that the total of storage and transit time will by far exceed the operating time of the Mechanism.

FINAL SELECTION OF MATERIAL

The final selection of a single gasketing material was made on the following bases:

1) Over-all Superiority

An arbitrary numerical value was assigned each general rating as follows:

Excellent: 4; Very Good: 3; Good: 2; Fair: 1; Poor: 0.

TABLE II

***Summary of Observed Maximum, Probable, and Recommended Testing Climatic Conditions**

Location		Thermal Range High °F	Thermal Range Low °F	Moisture Range High % RH	Moisture Range Low % RH	Notes
1. Ground, world-wide	Obs.	+140	-90	100	5	
	Prob.	+125	-65	97	0.5	
	Test.	90 to 125	-40 to -65	100 @ 85F	5 @ 125F	
2. Arctic, winter	Obs.		-90	100	0.5	Low RH observed only in heated arctic storehouses
	Prob.		-65	100		No low RH specified for outdoor applications
	Test.		-40 to -65	100		100% RH below 32 F
3. Desert	Obs.	+140		100	5	
	Prob.	+125		100	5	
	Test.	90 to 125			5 @ 125F	
4. Moist Tropics	Obs.			100		
	Prob.	+95		97		No low RH specified
	Test.	75 to 95		100 @ 80 F		No low RH specified
5. Short-term storage, transit	Obs.	+160	-80	100	0.5	0.5% RH in heated arctic storehouses
	Prob.	+160	-80	100	2.0	
	Test.	90 to 160	-40 to -80	100 @ 80F	2 @ 160	
6. Shipboard, world-wide	Obs.	+100		100		Maximum ambient air temp. only
	Prob.	+100	-20	100	93	No low RH specified
	Test.	90 to 100	-20	100		

***Taken from Ref. (1).**

TEMPERATURE, °F

Mechanism No.	R. T.				120			140			160		
01	-7.0	-19.0	-9.0	-4.0	-13.0	-9.0	-9.0	-8.5	-9.5	-9.0	-9.0	-3.0	-3.0
03	+21.5	+25.5	+20.5	+22.5	-1.5	+3.5	+3.5	+21.0	-6.5	-1.5	-7.5	+4.5	+1.5
07	-26.0	-23.0	-24.0	-23.0	-23.0	-	-24.0	-32.0	-15.5	-14.5	-14.5	-11.5	-13.5
08	+14.5	+17.5	+13.5	+13.5	+4.5	+9.5	+6.5	+0.5	+3.5	+5.0	+8.5	+5.0	+5.5
27	-26.0	-26.0	-26.0	-27.0	-26.0	-	-	-	-25.0	-	-25.0	-25.0	-23.0
36	+17.0	+18.0	+16.0	+15.0	-2.0	-1.0	-3.0	-4.5	-6.0	-1.5	-6.0	+3.0	+2.0
45	+4.0	+4.0	+4.0	+5.0	+3.0	+5.0	+5.0	+2.0	+2.0	+5.0	+3.0	+6.0	+6.5
50	+10.0	+9.0	+8.0	+9.0	+4.0	+2.0	-	+3.5	+2.5	+7.0	+4.0	+2.0	-1.0
52	-	-	-	-	-	-	-	-	-	-	-	-	-
59	-	-	-	-	-	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-8.0	-1.5	-2.0	-0.5	+8.5	+8.5
67	+7.0	+8.0	+7.0	+7.0	+2.5	+2.0	+2.0	+1.0	+1.0	+4.0	-1.5	+5.0	+4.0
76	+12.0	+9.0	+7.0	+3.0	+5.0	0.0	+6.0	+6.0	+7.0	+5.0	+1.0	+5.0	+3.0
85	-	-	-	-	-	-	-	-	-	-	-	-	-
86	-	-	-	-	-	-	-	-	-	-	-	-	-
87	-5.5	-4.5	-5.5	-4.5	-3.5	-0.5	-0.5	-1.5	-2.5	-1.5	-1.5	+2.5	-0.5
90	-	-	-	-	-	-	-	-	-	-	-	-	-
94	-	-	-	-	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-	-	-	-	-
97	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE III

General Characteristics of Synthetic Rubber Materials

	Relative Properties	Buna-N	Neoprene	Thiokol	Silicone	Ref.
1.	Maximum temperature limit, upper, °F	300	300	160	450	5
2.	Maximum temperature limit, lower, °F	-65	-65	-65	-120	5
3.	Resistance to long term heat aging	G	G	P	E	6
4.	Resistance to "shelf aging"	G	G-VG	F-G	E	5
5.	Resistance to permanent set	VG	P-E	P	G	5
6.	Speed of recovery from permanent set condition	F	F	P	G	6
7.	Resistance to low temperature hardening	F-G	F	P	E	6
8.	Resistance to water absorption	E	F	E	G	5, 6
9.	Resistance to hydrocarbons	VG	F-G	E	F	5, 6
10.	Resistance to solvents, general	F-G	F-G	E	F	5, 6
11.	Resistance to vapor transmission	F-G	VG	G	F	
12.	Resistance to silicones	E	E	E	E	8
13.	Resistance to tearing	F	G	P	P	5
	Arbitrary Numerical Scoring					
	E = 4; VG = 3; G = 2; F = 1; P = 0	26	25	20	26	

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Using this method of rating, the following scores were obtained:

Buna-N: 26; Neoprene: 25; Thiokol: 20; and Silicone: 26.

On this basis the Thiokol material was arbitrarily eliminated from consideration. To support this decision, the poor relative ratings in maximum temperature, resistance to permanent set, poor recovery, high cost and relatively low availability were factors in the rejection.

2) Specific Superiority

No further rejection on the basis of over-all superiority could arbitrarily be made at this point, and, therefore, specific faults considered to be disqualifying for this particular application were the next points of discrimination. The Silicone materials were summarily eliminated from consideration on the basis of their relatively low resistance to fuels, solvents, water-vapor transmission and physical tearing, in addition to high cost and relatively difficult procurement. The choice between Buna-N and Neoprene materials remained as a difficult one, but, in the final analysis, Neoprene was eliminated for reasons of its relatively lower resistance to fuels and solvents, and the slightly lower resistance to permanent set, low temperature hardening and water absorption than the Buna-N materials. Buna-N then remained as the material to be used for gasketing the Mechanism.

Specific investigation into the grades of Buna-N materials available, as shown in Specification MIL-R-003065A (ORD), "Rubber and Synthetic Rubber Materials; Mechanical and General Purpose," indicated that the following material was satisfactory for the anticipated conditions previously outlined:

Buna-N material, sheet stock 1/16" thick, Type S (oil resistant), Class SB (low volume swell), Grade No. SB-625-B (Durometer "A" hardness 60 $\pm$5, 2500 psi minimum tensile strength, 35% maximum compression set).

DESCRIPTION OF TESTS

A series of tests were run to determine the relative validity of data published for the resistance of synthetic rubber gasketing materials when exposed to various fuels and solvents. These fuels, solvents, and other liquids were chosen for both their general availability and inflammability, on the assumption that these would be those most commonly encountered in field usage to produce fires and explosions. In general the tests confirmed the relative data supplied by various manufacturers, but it is believed that the natural tendency was present for those firms to minimize conditions that were adverse to their products. The summary of results for these tests is presented in Table IV.

A second series of tests were run to determine whether or not both the original Corprene and the Buna-N gaskets could withstand more than the client-specified external water pressure of 25 feet. The results of these tests, which were run at room temperature in fresh water, indicated that the case, when gasketed and sealed as recommended, would successfully withstand 50 psig external pressure, equivalent to some 100 feet of water. However, the 1/32" thick gaskets were more easily sealed than were the original ones of 1/16" thickness. A sealing compound of "Permatex No. 1" was used to seal all threads, and Dow-Corning silicone grease DC-11 was used to seal and lubricate the glands. Even under these conditions of extreme pressure, the water vapor transmission, as shown by a color-indicating desiccating agent, "Drierite," within the case, was not considered serious over a 48-hour period. A similar test for moisture, using sodium hydroxide pellets as a desiccant, yielded the same indication of relatively low vapor transmission.

A series of tests were run to determine whether or not the Corprene and Buna-N gaskets could withstand, at room temperature, an external air pressure equivalent to 40,000 feet altitude. With the case filled with water, closed, sealed and placed in a bell jar, a reduction in pressure corresponding to that altitude was produced about the case. No leakage or gasket distortion was observed over a 30-minute period.

During the low temperature test runs to determine the watch movement lubricant performance, severe sticking of the Corprene back plate cap washers was experienced. In other cases it was impossible to remove the back cover plate cap by hand after it had been allowed to stand undisturbed for some three or four weeks. In both cases, this sticking was responsible for the rolling and breaking of the flat washer material when the cap was finally removed. As a result, a single prototype was made for a new cap making use of a commercially available

TABLE IV

Summary of Changes in Physical Properties of Various Gasket Materials When Immersed for 24 Hours in Various Liquid Solvents, Fuels, Lubricants, etc., at Room Temperature

	Liquid Solvents, Fuels, Lubricants, etc.	Corprene DC-100 ΔWt. %	Corprene DC-100 ΔVol. %	Corprene DC-100 Notes	Buna-N ΔWt. %	Buna-N ΔVol. %	Buna-N Notes	Thiokol FA 3000 ΔWt. %	Thiokol FA 3000 ΔVol. %	Thiokol FA 3000 Notes
1.	Toluol, technical	120	190	SBW	81	81	B	31	71	
2.	Benzene, technical	110	220	SBW	79	130		49	90	
3.	Xylol, technical	190	260	SBW	82	100	BW	26	49	
4.	Acetone, technical	16	24		49	70		9	28	
5.	Ether, petroleum, technical	7.7	22		6	-16		0.25	3	
6.	Turpentine, gum	91	120	BW	18	25		8	17	G
7.	Gasoline, regular, Amoco	45	42		2	4		3	14	
8.	Gasoline, hi-test, Amoco	53	87		4	6		3	8	
9.	Gasoline, hi-test, Shell	61	82		5	4		4	14	
10.	Kerosene, Shell	26	31		-1	1		2	3	
11.	Diesel Oil, Shell	32	29		6	19		3	8	
12.	Motor Oil, detergent, Shell X-100	2	-8		-5	1		-0.1	6	
13.	Mineral Oil, USP	0.6	3		-4	-4		-0.1	3	
14.	Silicone Oil, Dow-Corning DC-	1	0		7	0		0.4	6	
15.	Vegetable Oil, "Mazola"	3	13		-5	-4		-1	0	
16.	Alcohol, methyl, technical	5	7		-4	-16		6	14	

NOTES:

S = Spongy surface
B = Brittle, breaks easily when bent 180° on itself
G = Gummy surface
W = Weak, breaks easily in tension

Buna-N, O-ring closure. This closure allowed for a wide range of positive sealing pressures from very light to extremely heavy; this effect would allow for less critical standards of cap closure by field personnel. At low temperatures the Buna-N O-ring closure operated satisfactorily, allowing for positive sealing at temperatures as low as -55°C (-64°F), although at that temperature the speed of recovery from compression set was somewhat slower than at room temperatures. This condition, however, is common for all rubber-like gasketing materials except the silicones.

A final series of tests were run to determine the suitability of the "Permatex No. 1" compound as a thread sealer for this particular application. This material, when allowed to harden, did not exhibit any appreciable tendency to crack at temperatures as low as -65°F nor soften and flow at temperatures as high as 160°F. It did not exhibit plastic flow when, used as a sealer in actual service, it was subjected to pressures of 50 psig under water. It was found to be soluble at room temperature in acetone and aromatic solvents and slightly soluble in turpentine and methanol. The common fuels (gasoline, kerosene, diesel oil, fuel oil), lubricants (motor oil, mineral oil, silicone oil) and vegetable oil showed no adverse effect.

While acetone and the aromatic solvents do exhibit a softening effect on the "Permatex No. 1" material, this is not considered to be a totally disqualifying fault. Since the sealing compound, when used in the actual Mechanism case, will be exposed only on a small area and will be backed by relatively great depths, it is believed that it will withstand the solvent action of these materials for the required operational time of approximately 24 hours.

REFERENCES

1) Environmental Protection Branch, R & D Division, Office of the Quartermaster General, U.S.Army, REPORT NO. 146: CLIMATIC EXTREMES FOR MILITARY EQUIPMENT, November 1951.

2) Specification MIL-STD-210, "Climatic Extremes for Military Equipment," June 1, 1953.

3) ARTHUR D. LITTLE, INC., Test Results.

4) Original Specifications for 24-Hour Clockwork Delay Mechanism.

5) Materials & Methods, July 1953, Page 87.

6) Graton & Knight Co., Worcester, Mass., Pamphlet No. 1000-8-52-EM, Page 5.

7) Green Rubber Company, Cambridge, Mass.

8) Dow-Corning Corp., Bulletin No. 6-3000, November 1952.

APPENDIX F

ADL INTERIM REPORT NO. 3

"INVESTIGATION OF THE CAUSES OF FIRING MECHANISM FAILURES IN THE 24-HOUR CLOCKWORK DELAY MECHANISM"

February 15, 1955

INTERIM REPORT NO. 3

INVESTIGATION OF THE CAUSES OF FIRING MECHANISM FAILURES IN THE 24-HOUR CLOCKWORK DELAY MECHANISM

QK-15-529

C-59411

ARTHUR D. LITTLE, INC.

FEBRUARY 15, 1955

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INTERIM REPORT NO. 3: INVESTIGATION OF THE CAUSES OF FIRING MECHANISM FAILURES IN THE 24-HOUR CLOCKWORK DELAY MECHANISM

INTRODUCTION

From the very beginning of the functional and timing tests conducted on the original samples of the 24-Hour Clockwork Delay Mechanisms, as delivered to Arthur D. Little, Inc., from Thomaston Special Tool Company, it became increasingly apparent that there were several sources of mechanism failure to be considered. In view of the fact that the mechanism must function satisfactorily in the field with probably no "run-in," the elimination of all possible points of failure was of the utmost importance.

These failures were characterized by the fact that they prevented the mechanism from either completing a time delay run or, having successfully completed the run, firing at the end of the run. Both experience gained and inspections performed during the testing program indicated that these failures could be divided into two (2) general classes. The first, those failures preventing successful completion of a delay run, were found to lie entirely within the watch movement; the second, those preventing firing after a delay run, were found within the firing linkage system. There was no indication that failure in one system caused failure in the other, provided the mechanism was correctly cocked at the beginning of a run.

The causes of watch movement failure were found to be entirely detectable by the use of both the "Watchmaster" timer and a functional run-in period. The second class of failure, however, was somewhat more difficult to detect, isolate, and describe. It is with this second class of failure that this report is concerned.

CONCLUSIONS

1) The 24-Hour Clockwork Delay Mechanism is subject to five (5) distinct types of failure within its firing linkage system.

2) Of these five (5) types, four (4) can be reduced to zero incidence by the application of special assembly methods and inspections by the Contractor performing the final assembly and inspection.

3) The remaining failure type can be successfully reduced to zero incidence by the use of proper operating techniques on the part of the field operator.

RECOMMENDATIONS

1) That the Striker (Part 210b-423) and Striker Spring (Part 210b-424) be lubricated, prior to assembly in the mechanism, by a coating or plating of molybdenum disulfide, applied as a lubricant-in-solvent dipping operation.

2) That the Latch Assembly (Assby 210b-301) be lubricated, after assembly with the Sear Lever (Assby 210b-202) but before final assembly into the mechanism, with molybdenum disulfide, applied as either a dry spray or brushed coating.

3) That the Tripping Lever Spring (Part 210b-428) be wound at assembly to deliver a minimum of 7 grams force at the point at which the Tripping Lever rides the Hour Disc (Part 210a-453), and that the force at this point be checked on each mechanism as a part of the final assembly inspection.

4) That the Tripping Lever Stud (Part 210b-429) position be gaged closely during assembly to prevent binding of the Tripping Lever within the Positioning Bracket (Part 210b-430) during operation, and that the clearance of the Tripping Lever within the Positioning Bracket be checked on each mechanism as a part of the final assembly inspection.

5) That the Instruction Sheet contain a specific paragraph to instruct field operators in the proper operation of the start-stop system; in particular, that operators back off the start-stop knob at least one full turn after having brought the positive starter spindle to the fully retracted position against its stops.

INVESTIGATION OF FAILURES IN THE FIRING LINKAGE SYSTEM

The investigation and detection of faults causing various types of failure in the firing linkage system was of necessity a rather long one, since the symptoms of each fault was the same, namely, failure of the mechanism to fire after a successful delay run.

The first indication that such failures existed came early in the functional and timing tests conducted on the original samples delivered from Thomaston Special Tool Co. These initial faults were recognized and immediately either corrected or rendered ineffective so that testing could continue. At this early date, additional failures to fire were attributed to the same causes and the same corrective actions were taken. In the following description, these failures are designated as Types I and II.

As the testing experience became more extensive, however, it was apparent that these original faults I and II could not possibly account for the continuation of failures to occur. This situation was met by a second and more extensive investigation for possible causes of failure within those mechanisms specifically known to be subject to firing linkage malfunctioning. This inspection indicated that the failure of the linkage to trip, even after the tripping lever had fallen, was the result of low tripping lever spring torsion, described as Type III.

Continuation of firing linkage failures, however, indicated that, although three distinct sources of trouble were already detected and partially corrected, there were still more failures which could not have been caused by those already known. At this time an additional source of difficulty was isolated in the form of tight Latch Assemblies and are designated as Type IV failures in the following description.

Determination of the overriding fault was finally made when a mechanism which previously exhibited consistent failure in the firing system was observed to fire accidentally and successfully when the positive starter was only partially cleared. This indicated that the start-stop system and its associated latch stop system were in some way responsible for the continued failures. Upon final analysis of this fault, designated in this report as Type V, it was determined that the Latch Stop Spring (Part 210b-447) was being forced to bite into the Latch Assembly, preventing it from being tripped under the impact of the Tripping Lever. This single fault was found to be the major culprit, causing by far the greatest number of failures in the firing linkage system. Since the symptoms of Types III, IV, and V failures were all alike, however, it was only by a process of elimination that this last, most frequent cause was brought to light. Under test conditions in which this biting of the Latch Stop Spring was controlled, this belief was confirmed and further failures of the firing linkage system were not observed.

DESCRIPTION OF FAULTS CAUSING FAILURE

Type I: Sear Binding

The earliest failure observed to occur was that of the sear failing to release the striker after the entire firing linkage had been properly released. This fault was recognized immediately because of the clear symptoms involved, namely, binding at a single point. Repeated operation of the firing linkage system tended to reduce and, in cases of numerous operations, eliminate this failure, probably because of the polishing action of the sear against the striker. Since it is quite probable, however, that mechanisms will not be "run-in" after the initial inspection, the elimination of this source of trouble was sought in a more positive manner.

The cause of this failure was found to be a slight roughness of the sear face, which, when mated with tool marks on the striker face, completely prevented relative sliding between the two pieces . Lubrication of the striker with molybdenum disulfide, applied as a film or plating by dipping in Molykote M-88, completely eliminated this failure.

Type II: Tripping Lever Binding

At the same time as Type I failure was observed, it became apparent that a second source of failure was to be had in the binding of the tripping lever in the positioning bracket during the cocking operation. When the tripping lever is cocked, it is forced through the Hour Disc slot to a position considerably higher than that which it will occupy during the actual running of the mechanism. When the tripping lever is either slightly bent, or positioned either high or low on its mounting stud, it tends to be caught in and bound by the positioning bracket during the cocking operation. If this binding is severe, the tripping lever will not be driven down to contact the Hour Disc when the mechanism is started. This condition quite naturally prevents the tripping lever from ever dropping through the Hour Disc slot when the latter is presented at the end of a time delay run.

This condition was partially eliminated during the test program by the bending of the tripping lever, either up or down as required, to center it and prevent further binding in the locating bracket slot. The cause of this condition, however, is believed to lie in the original positioning of the tripping lever stud, which determines the final location of the tripping lever with relation to the locating bracket. In the final assembly inspection, however, it should be quite satisfactory to bend the tripping lever slightly to eliminate this fault should it be found to exist.

Type III: Low Tripping Lever Spring Torsion

Continued failures of the firing linkage system indicated that other sources of trouble must exist, the symptoms of which were the failure of the latch assembly to fall clear, releasing the sear, even after the tripping lever had been driven against it. The immediate reaction in this situation was to increase the spring torsion, thus causing the tripping lever to deliver a heavier blow to the latch assembly. This corrective measure reduced the incidence of failures of this type to some degree, but did not completely eliminate them. Increasing of the spring torsion to the point where the spring was wound solid did nothing to increase the reliability of firing; at this point it became obvious that there must yet be some other source of trouble which showed these characteristic symptoms.

Later experience gained in the isolation of Type V faults, however, indicated that low tripping spring torsion was practically negligible if it is above the lower critical limit stated in the Recommendations Section of this report.

Type IV: Binding Latch Assembly

Symptoms similar to Type III were found to be common to the situation in which the latch assembly bound on the sear arm at the pinned joint. Under these conditions the falling tripping lever also failed to dislodge the latch and allow the sear to release the firing pin. Disassembly of the mechanisms believed to be subject to this trouble, however, showed that this hypothesis, while actually true, could not account for the large number of continued failures. Only one (1) Latch Assembly was found to be stiff enough to cause this failure; it was eliminated by mechanical working of the joint and lubrication with powdered molybdenum disulfide.

Type V: Latch Stop Spring Binding

Only after the exhaustion of all other possible sources of failure was the possibility of latch stop spring binding considered. Its suggestion came as the result of a chance observation of the successful firing of a mechanism which had previously shown continuous failure under similar operations. It was determined that under the conditions of successful operation, however, the start-stop system had been only partially backed off, while previous operation had been made with this system fully cleared against its positive stop. Close observation showed that under the latter conditions the latch stop spring, held by the latch stop, was being deflected downward toward the latch when the start-stop system was brought fully tight against its stop at the end of its travel. When the latch stop was backed off by means of turning the start-stop knob one full turn back toward the "STOP" position, the latch stop spring was again returned to its normal position.

Under the conditions in which the latch stop spring was deflected downward, the lower edge of the spring, being square and sharp, was forced to bite into the Latch Assembly, effectively "freezing" it in position against the impact of the tripping lever. In all cases of this failure, the backing off of the start-stop screw relieved the binding of the spring against the latch and completely eliminated the failure. Investigation of the frequency of this type failure indicated that it was this, rather than Types III and IV, which had been causing by far the greatest number of failures in the firing linkage system. This fact was confirmed by the testing of eighty three (83) sample mechanisms; in all cases except one (1), and where Types I and II failures did not exist, the technique of backing off the start-stop knob corrected all malfunctions. From this it is to be concluded that Types III and IV failures were masking the actual cause of the largest number of failures. Further testing indicated that no other failures could be induced when those outlined above had been eliminated.

RESULTS OF TESTS

Type Failure Tested	No. Samples Inspected	No. Failures This Type
Type I	83	6
Type II	83	7*
Type III	83	2
Type IV	83	1**
Type V	83	20***

*Seven (7) critical faults, causing failure of firing system; also observed were four (4) cases of non-critical binding, in which firing was successful but cocking operation was difficult.

**Did not fall into position by gravity during the cocking action; later found to be stiff enough to have prevented firing except under the most heavy impact possible from the tripping lever.

***These failures obtained under controlled conditions, in which the start-stop system was taken up as tightly as possible against the stops, tending to drive the latch stop spring down as far as possible short of breakage.

APPENDIX G

Memorandum Report on Time-Temperature Trials Using Nyvolube "A" Oil

MEMORANDUM

To: H. F. Knight - Maynard Case: 59411 Date: March 22, 1955 Page: 1.

Subject: Temperature Trials

Three groups of 20 mechanisms were calibrated by four runs at room temperature (75 F). Each group of mechanisms was then subjected to three runs at each of a series of test temperatures ranging from -40 F to 160 F. The conditions of the tests are described elsewhere. At the end of each run, the timing error was recorded. These data are tabulated in the Appendix to this memorandum. In what follows, we discuss conclusions which can be drawn from an analysis of these data.

I Average Error as a Function of Temperature

The average timing error calculated for all runs and all mechanisms at each temperature is shown in Table I, together with the standard deviation of the distribution of individual results around this mean. The standard deviation is a measure of the uniformity of the results. As will be shown below, the distribution of errors is satisfactorily represented by the normal (Gaussian) distribution function. For such distributions, approximately 68% of the results lies within one standard deviation on either side of the mean value.

The data from Table I are plotted in Figure I. Notice that at temperatures of zero and above, the mean is essentially constant (at -1 minute) and the standard deviation does not vary appreciably from 8.5 minutes. At -30°, the average error has dropped to approximately -17 minutes and at -40°, the average error is approximately -24 minutes. At the same time, the standard deviation of the distribution of individual errors around this mean has increased to 12 and 17 minutes respectively, indicating a wider spread in the results.

The initial calibration runs at room temperature showed a fairly wide distribution of results for each mechanism. Therefore, we have computed the results of each of the test runs as the change in timing error from the average on the calibration runs. That is, we have subtracted from each of the results the average error for each mechanism at 75 F. These results are shown in Table II and in Figure II. Notice that the same general results are shown as were shown in the plot of the raw data.

The mechanisms in Group 3, for the high temperature runs, were apparently more erratic in their behavior than the mechanisms in the other two groups. There appears to be a drop of about 5 minutes in the average error for temperatures 120° and above. This drop is due almost entirely to mechanisms number 03, 08, and 36, which showed a high average error on the calibration runs but which settled down to a very small error during the test runs. When the results for these three mechanisms are omitted in the analysis, there is no apparent change in the average timing error.

TABLE I

AVERAGE TIMING ERRORS

Group	Temperature (°F.)	Mean Timing Error (Minutes)	Standard Deviation (Minutes)
I	75°	-1.87	7.45
	30°	-0.58	5.99
	0°	-2.32	8.59
	-30°	-17.10	11.79
	-40°	-24.22	17.20
II	75°	+1.00	6.08
	50°	+2.22	8.36
	100°	-0.50	8.23
III	75°	+1.54	15.60
	120°	-1.79	9.22
	140°	-2.23	9.67
	160°	-1.55	9.15
Averages:	All Runs	-2.19	11.10
	Calibration Runs (75°F.)	+0.02	8.57
	Test Runs	-3.48	11.55
	Test Runs 0°F. and Above	-0.98	8.46

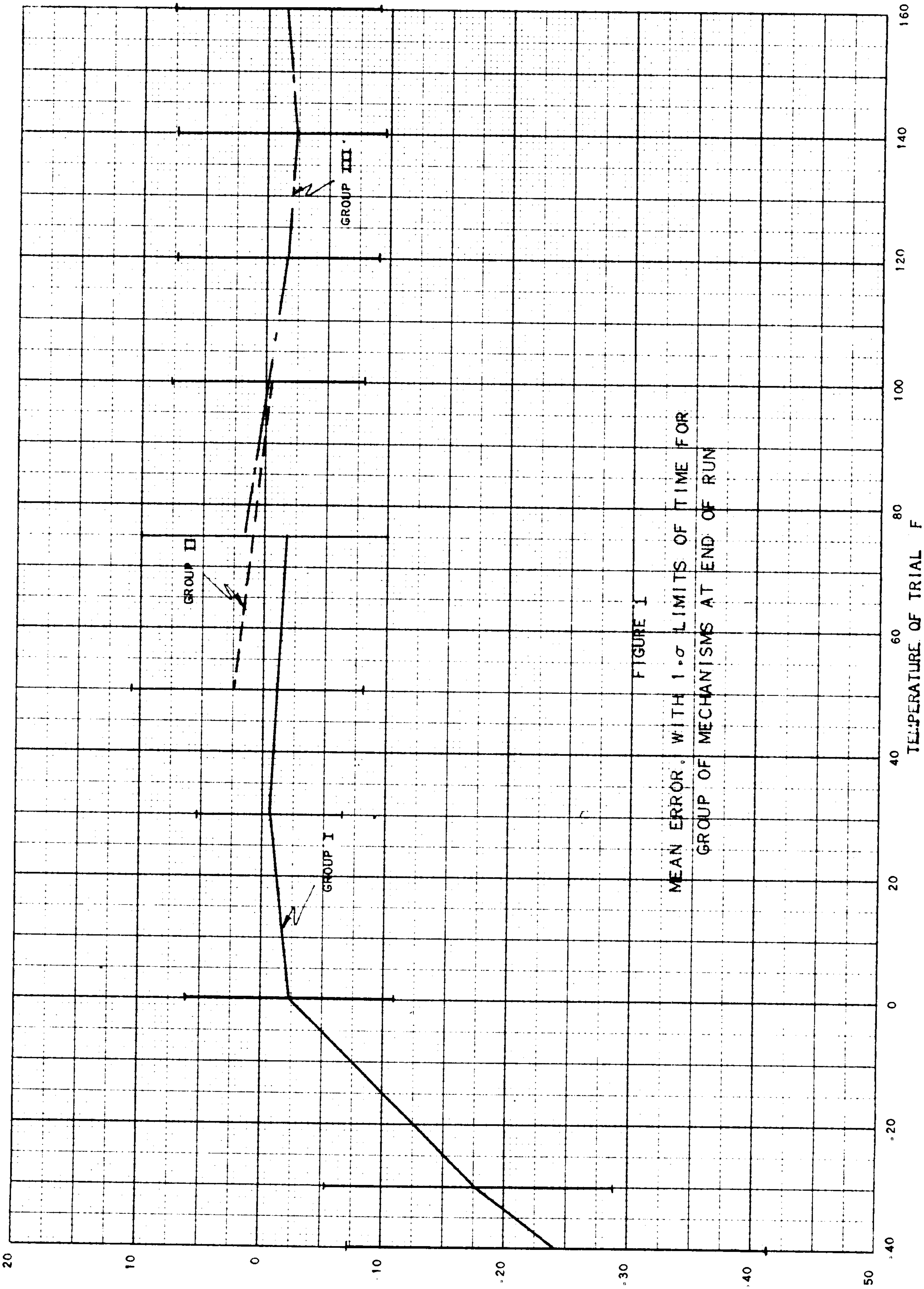

FIGURE I

MEAN ERROR, WITH 1 σ LIMITS OF TIME FOR GROUP OF MECHANISMS AT END OF RUN

TABLE II

AVERAGE CHANGE IN TIMING ERROR FROM AVERAGE OF CALIBRATION RUNS

Group	Temperature (°F.)	Mean Change (Minutes)	Standard Deviation (Minutes)
I	30°	+0.79	4.97
	0°	-0.33	8.87
	-30°	-16.33	10.25
	-40°	-23.76	11.57
II	50°	-0.29	9.40
	100°	-1.48	9.45
III (All Mechanisms)	120°	-5.70	8.18
	140°	-5.44	8.85
	160°	-5.35	12.03
III (Except Nos. 03, -8, 36)	120°	-1.30	3.15
	140°	-0.55	3.27
	160°	+0.88	6.08

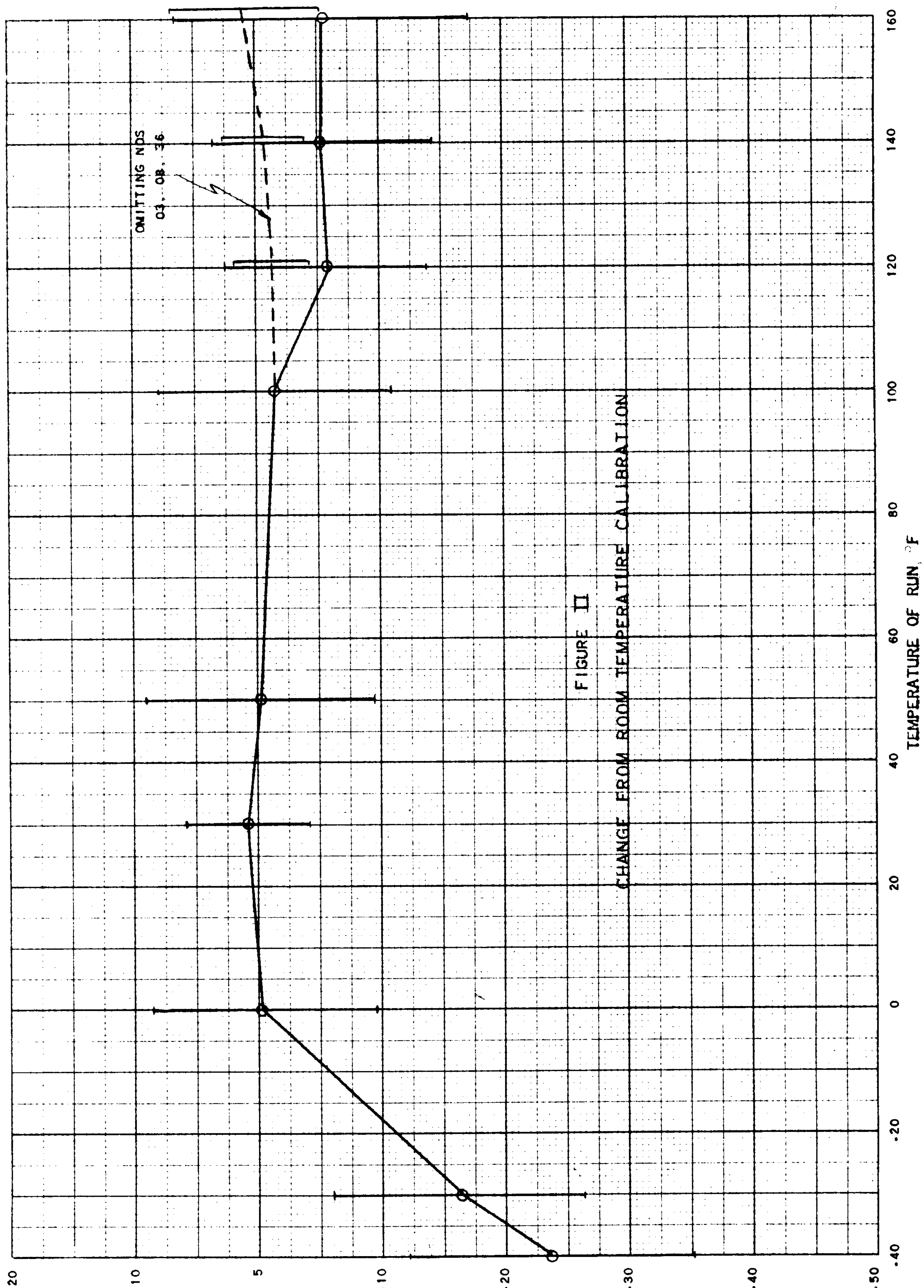

FIGURE II

CHANGE FROM ROOM TEMPERATURE CALIBRATION

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Subject: Temperature Trials

Conclusion

There is no detectable effect of temperature on timing errors for temperatures between 0° and 160°F. There is a marked drop in the value of the average error at temperatures below 0°, accompanied by a significant increase in the dispersion of errors around their mean value.

II Reproducibility

It will be noted that whereas the average error at room temperature ranges from -26 to +22 minutes, for the various mechanisms, the errors on repeated runs for any one mechanism generally lie within a minute or two of each other.

Conclusion

The results obtained on these tests are significant in that repetitions tend to reproduce results which are much closer together than the difference between errors for different mechanisms.

III Accuracy

As was noted above, the mean timing error at temperature above 0° is approximately -1 minute. The standard deviation is approximately 8.5 minutes. This means that approximately 68% of all results lay between -9.5 minutes and +7.5 minutes.

In order to illustrate more completely the distribution of results, we have plotted in Figre III the distribution of error for all mechanisms on the four calibration runs at room temperature. The horizontal axis of this graph is the error in minutes. The vertical axis is the percentage of all mechanism-runs for which the error was less than or equal to the error shown on the horizontal axis. The scale used on the vertical axis is such that a normal (Gaussian) distribution would be plotted as a straight line. Notice that the data cluster about the line quite well.

In Figure IV we have plotted a similar distribution for the errors on test runs for temperatures 0° and above. The distribution of errors is the same on these test runs as it was at room temperature.

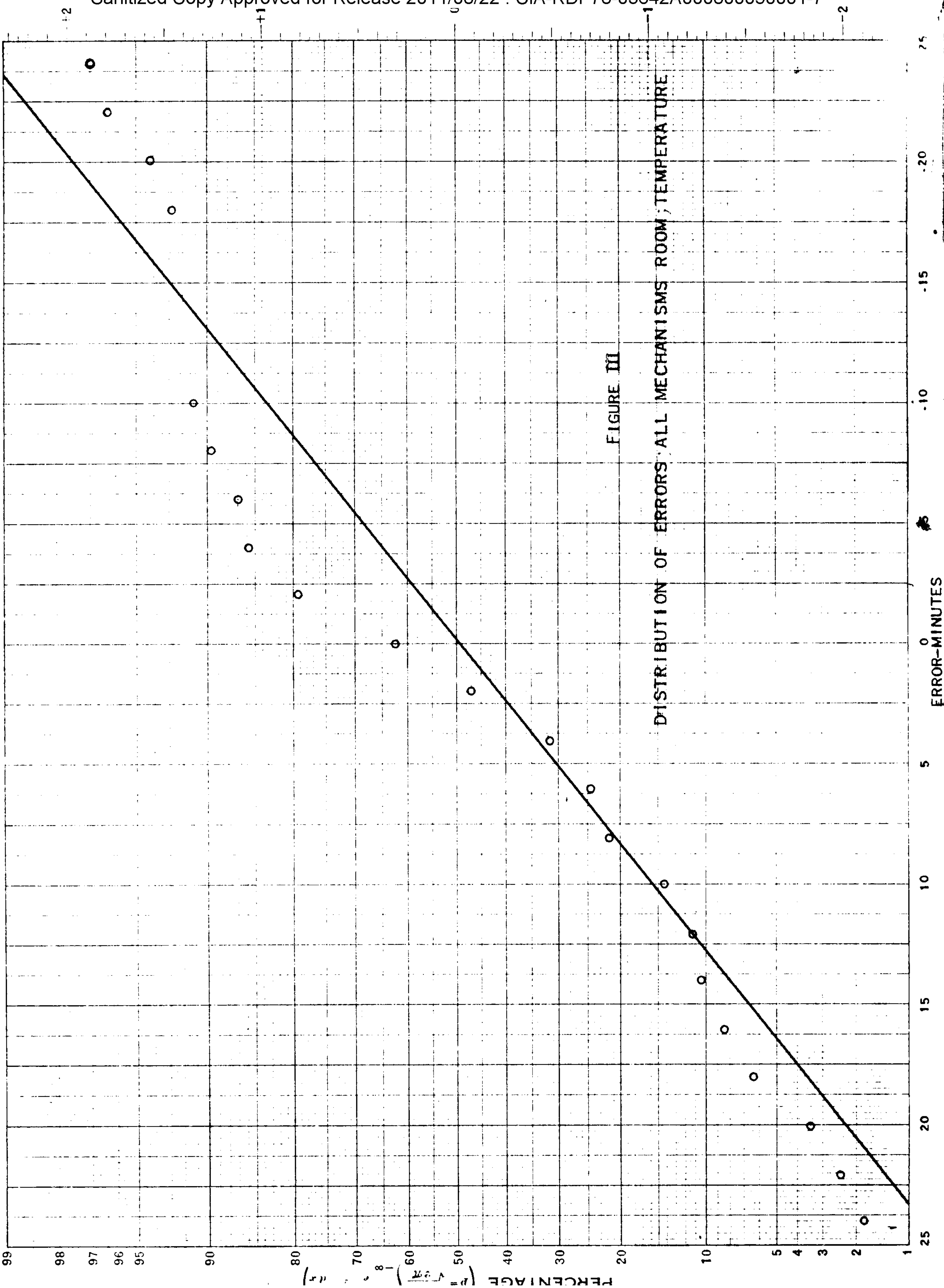

FIGURE III

DISTRIBUTION OF ERRORS ALL MECHANISMS ROOM; TEMPERATURE

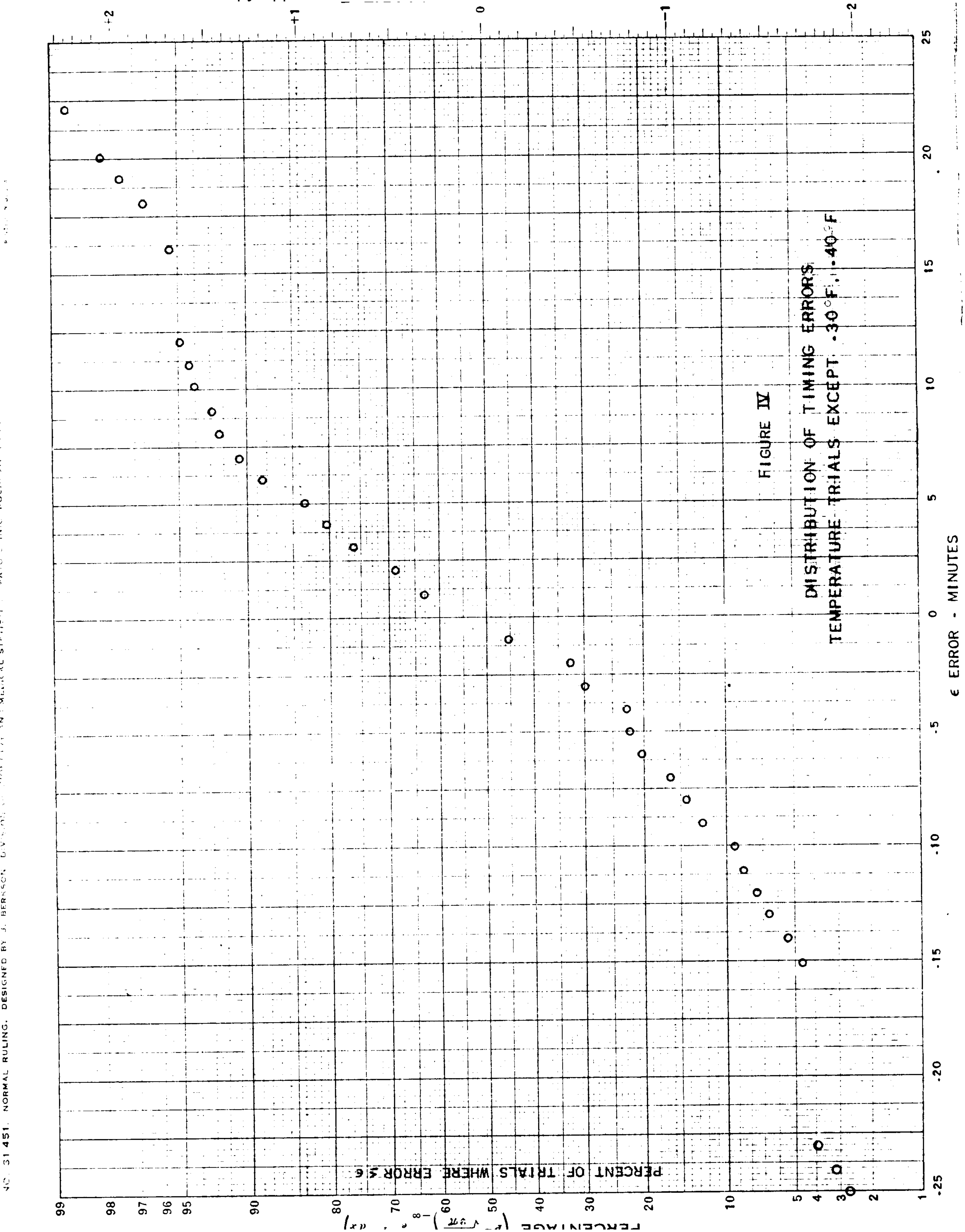
FIGURE IV
DISTRIBUTION OF TIMING ERRORS
TEMPERATURE TRIALS EXCEPT -30°F, -40°F
ε ERROR - MINUTES
PERCENT OF TRIALS WHERE ERROR ≤ ε

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Subject: Temperature Trials

Conclusion

The timing errors at temperatures above 0° are approximately normally distributed with a mean approximately -1 minute and a standard deviation approximately 8.5 minutes. Thus, it is to be expected that 68% of the time the error at the end of an operating run would be within 8.5 minutes on either side of the correct time. Approximately 95% of the time results would fall within 17 minutes either side of the correct value.

IV Operability

Although there were 20 mechanisms selected for each group, in no case would all 20 run to the completion of a test. Figure V shows the number of mechanisms for which an error was recorded on the test runs at the various temperatures. For temperatures 0° and above, the average number of mechanisms which ran to completion was 12.8 (64%). For the two lowest temperatures, only 31% of the mechanisms operated to completion.

Conclusion

There is no apparent change with temperature in the percent of mechanisms which operate to conclusion except at -30° and -40°F. when the percent of mechanisms which operates to conclusion is cut in half.

V Calibration

Of the total group of 45 mechanisms which completed one or more calibration runs, 25 had average errors $\leq \pm$ 3 minutes at room temperature. Only 28% of these mechanisms later gave readings greater than $\pm$ 5 minutes in error on test temperature runs (-30 and -40° excluded); 42% of the entire 45 mechanisms which were calibrated gave readings on test runs larger than 5 minutes in error.

Conclusion

Calibration at room temperature may provide a satisfactory basis for selecting mechanisms which will materially reduce the variation in timing errors.

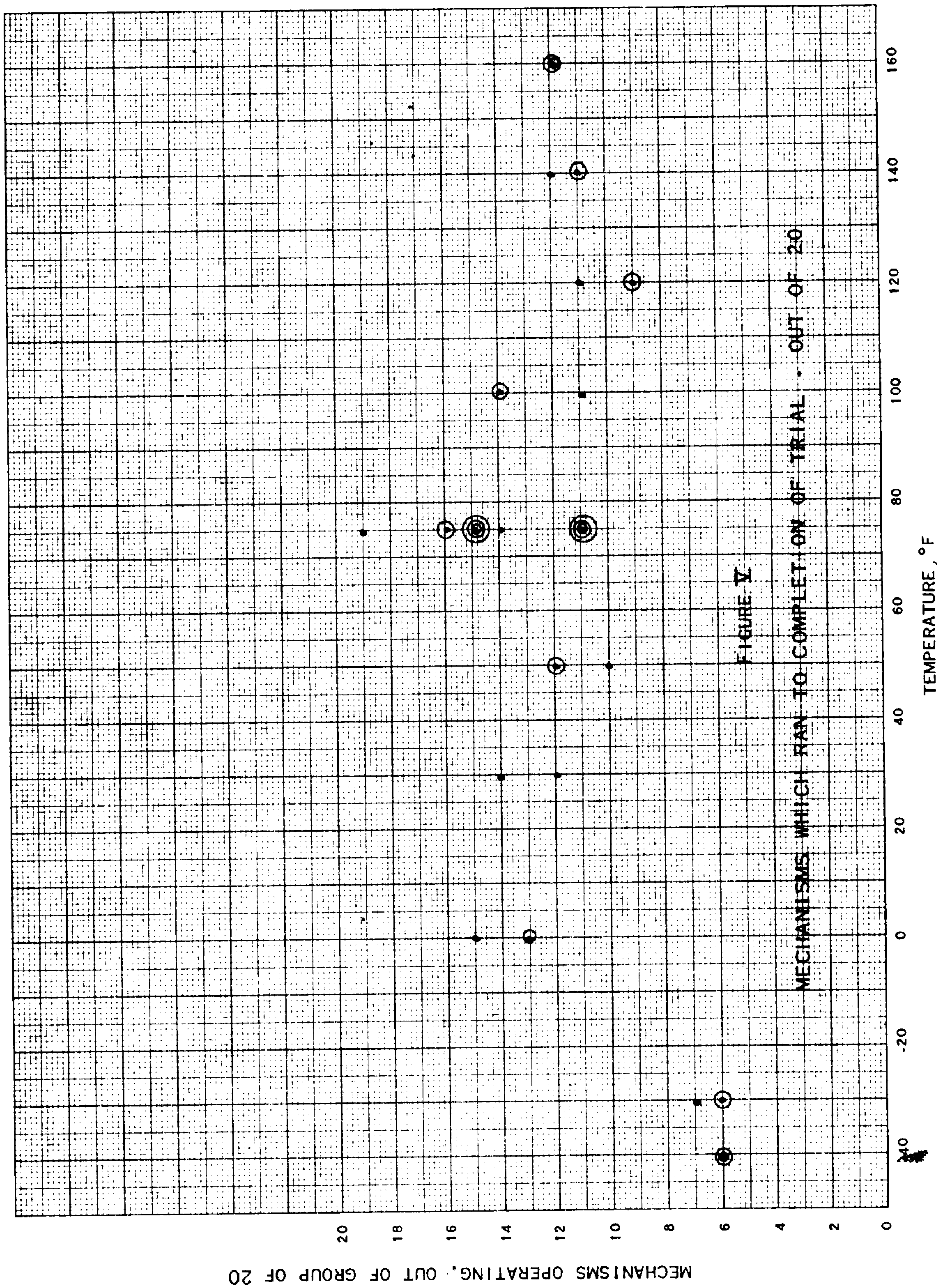
FIGURE V
MECHANISMS WHICH RAN TO COMPLETION OF TRIAL • OUT OF 20
TEMPERATURE, °F
-40
-20
0
20
40
60
80
100
120
140
160
MECHANISMS OPERATING, OUT OF GROUP OF 20
0
2
4
6
8
10
12
14
16
18
20

APPENDIX
TABLE I

TIMING ERRORS, IN MINUTES

Mechanism No.	TEMPERATURE °F. R. T.				30			0			-30			-40		
04	-0.5	-4.5	-3.5	-3.5	-7.0	-7.0	-6.0	-5.5	-5.5	-5.0	-	-	-	-	-	-
14	+1.0	-2.0	-3.0	-4.0	-6.0	-	-7.5	-10.5	-	-	-	-	-	-	-	-
15	-22.0	-20.0	-19.0	-21.0	-9.0	-5.0	-5.0	-8.5	-8.0	-5.0	-	-	-	-	-	-
31	-18.5	-	-	-23.5	-	-	-	-	-	-	-	-	-	-	-	-
34	-4.0	-2.0	-3.0	-2.0	-1.0	-1.0	-	-1.5	-2.0	-0.5	-	-	-	-	-	-
35	-3.0	-1.0	-2.0	-3.0	-6.0	-4.0	-5.0	-5.0	-5.0	-4.5	-13.0	-13.0	-23.0	-60.0	-23.0	-13.0
41	-	-	-	+3.0	-	-	-	-	-	-	-	-	-	-	-	-
42	-8.0	-8.0	-10.0	-10.0	-	-	-9.0	-8.0	-11.0	-9.0	-	-	-	-	-	-
51	-	+2.0	-	+1.0	0.0	0.0	+1.0	-11.0	-33.0	-	-	-	-	-	-	-
54	-	-	-3.0	-1.0	-0.5	+0.5	-1.0	0.0	-1.0	-3.0	-38.0	-25.0	-41.5	-60.0	-41.5	-25.0
57	+13.0	+11.0	+7.0	+8.0	-	-	-	-	-	-	-	-	-	-	-	-
60	+1.0	+3.0	+2.0	+1.0	+1.0	-	+0.5	-0.5	-4.0	+1.0	-	-	-	-	-	-
66	+2.0	-1.0	-1.0	0.0	0.0	+1.0	0.0	0.0	0.0	0.0	-28.0	-25.0	-30.0	-34.5	-30.0	-25.0
68	+1.0	+2.0	+2.0	+7.0	+1.5	+1.5	+0.5	+0.5	+1.0	+1.5	-3.0	-3.0	-5.0	-34.5	-5.0	-3.0
75	-3.5	-0.5	-0.5	-2.5	-	-	-	-	-	-	-	-	-	-	-	-
78	-1.0	+2.0	+7.0	-3.0	0.0	+0.5	0.0	0.0	0.0	0.0	-12.0	-	-	-	-	-
89	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
91	-3.0	-1.0	-2.0	-1.0	-2.0	0.0	-2.0	0.0	-1.0	0.0	-17.0	-14.0	-17.0	-27.0	-17.0	-14.0
92	-1.0	+1.0	0.0	+1.0	-1.0	+2.0	+0.5	+1.0	-0.5	0.0	-3.0	-9.5	-5.0	-9.0	-5.0	-9.5
100	-	+8.0	+7.0	+9.0	+17.0	+17.0	+17.0	+30.0	-	+18.0	-	-	-	-	-	-

Mechanism No.	TEMPERATURE, °F.									
	R. T.				50			100		
02	0.0	-3.0	0.0	-4.0	+5.5	0.0	-1.0	-3.5	-2.0	-2.0
06	-1.0	+2.0	+1.0	+1.0	+5.5	+4.0	0.0	+2.5	-	+2.0
39	-2.5	-0.5	-1.5	-2.5	-1.0	-	-	-6.5	-	-12.5
43	-3.0	-3.0	-2.0	0.0	-	-	-	-	-	-
44	-3.5	-3.5	-2.5	-2.5	+4.5	0.0	-1.5	-3.5	-2.5	+0.5
46	-	-	-	-	-	-	-	-	-	-
47	+4.0	+4.0	+5.0	+3.0	+7.5	-	-	+11.0	-	+10.5
55	+5.5	+4.5	+4.5	+6.5	+17.5	-0.5	+15.0	-2.5	+1.5	+0.5
56	-1.5	+1.5	+0.5	+0.5	0.0	5.0	-3.5	-7.0	-6.5	-6.5
62	-0.5	+2.5	+1.5	+1.5	+3.5	-1.0	+0.5	-7.0	-1.5	-3.5
63	-	-	-	-	-	-1.0	-1.5	-	-2.0	-
70	+2.0	+3.0	+1.0	+2.0	-	-	-0.5	+2.0	-	-1.5
72	-	-	-	-	-	-	-	-	-	-
74	-	-	-	-	-	-	-	-	-	-
79	-8.5	-5.5	-7.5	-9.5	-	-	-26.5	-13.5	-15.5	-12.0
82	+2.0	-3.0	+2.0	+2.0	+1.0	+2.5	+2.0	+2.0	+3.5	+3.0
83	-0.5	-0.5	-1.5	-1.5	+2.5	-	-6.5	-2.5	-2.0	-3.0
88	+18.0	+19.0	+18.0	+24.0	+5.5	-2.5	-	-1.0	0.0	0.0
96	-3.5	-3.5	-	-0.5	+9.5	+22.0	+19.0	+21.5	+22.0	+18.0
98	-	-	-	-	-	-	-	-	-	-